THE

ONTARIO WATER RESOURCES

COMMISSION

BASIC COURSE

FOR

SEWAGE WORKS OPERATORS

1968

BASIC COURSE

FOR

SEWAGE WORKS OPERATORS

June 17th to 21st, 1968

Ontario Water Resources Commission

Sewage Operators' Courses

Course I

Basic	1961	
Basic - repeat	1961	October 16-20th
Intermediate	1962	March 5-9th
Intermediate - repeat	1962	December 10-14th
Senior	1963	April 22-26th
Senior - repeat	1963	September 16-20th

Course II

Basic	1963	November 18-23rd
Intermediate	1964	May 25-29th
Senior	1964	December 7-11th

Course III

Basic	1965	May 31 - June 4th
Intermediate	1965	December 6-10th
Senior	1966	April 25-29th

Course IV

Basic	1966	December 5-9th
Intermediate	1967	May 15-19th
Senior	1967	December 4-8th

Course V

Basic	1968	June 17-21st

ONTARIO WATER RESOURCES COMMISSION

BASIC SEWAGE WORKS OPERATORS' COURSE

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

SEWAGE WORKS OPERATORS' COURSE
ONTARIO WATER RESOURCES COMMISSION

INTRODUCTORY STATEMENT BY MR. D. S. CAVERLY
GENERAL MANAGER, OWRC.

It is being increasingly recognized today that training must be an on-going programme. New ideas, new techniques, new situations all demand that we take advantage of every opportunity to become better informed in our areas of responsibility.

The Sewage Works Operators' Course is designed to that end. Introduced by the Commission in 1961, it serves a most useful purpose in the further training of plant operators.

May I take this opportunity, first of all, to welcome you to this course. I know that you will take full advantage of it. There will be opportunities for you not only to hear lectures and take part in discussions on subjects of direct interest to you, but you will also see some laboratory work and demonstrations in what is considered to be one of the finest water resources laboratories in the country.

THE ONTARIO WATER RESOURCES COMMISSION

Before discussing the contents of the course and matters related to it, I would like to tell you something about the OWRC and its objectives. The OWRC is a relatively new organization in the Province of Ontario. It is involved in a programme of major significance insofar as the development of this Province is concerned. It has a close relationship with other departments and agencies in the Province, and it is desirable that its functions and organization be understood in order to appreciate the nature of the work which it is attempting to do.

Formerly, the supervision of water works and sewage works in this Province came under the Department of Health and, more particularly, under that Department's Sanitary Engineering Division. When the Ontario Water Resources

Commission was established by legislation in 1956 this supervision was transferred from the Department of Health to the Commission. The legislation was amended in 1957 and in subsequent years as well, whenever the situation warranted it. The Commission is now operating under this 1957 legislation together with its amendments. While it is similar in some respects to legislation under the Public Health Act, it is considerably more far-reaching and gives the Commission wide authority to deal with sewage works and the problem of water pollution.

The Commission consists of six members, under whose direction policy is determined and the programme put into effect. The Commission maintains a staff of well trained personnel who act as advisers to municipalities and others throughout the Province. These men are specialists in a variety of fields relating to sewage and stream sanitation. It is hoped that there will always be close co-operation between the staff and the operators of sewage works. The papers given at this conference will be presented by members of the staff, and you will learn more about the activities of the Commission in this way. It is only through close co-operation between operators and the Commission that the best results can be obtained. The staff of the Commission are here to assist at all times in problems with may arise in the treatment of sewage and in the prevention of water pollution.

OBJECTIVES OF THE COURSE

It is well, at the outset of this course, to define objectives so that each will understand what is expected of him and what type of training is to be provided. Here is an unsurpassed opportunity for those in charge of sewage and waste treatment plants to learn about many subjects, to discuss problems with others in similar positions, and in that way, to have a full exchange of experience and ideas.

Our first objective is to train operators in the fundamentals of sewage plant operation. The programme of the Commission in pollution control can only be made effective if the operators are thoroughly trained and are alert to their

responsibilities. It is only possible in a course of this kind to deal with fundamental or basic subjects, but a thorough training in these will enable any operator to go further in his education and to learn much from day to day operation of his plant. Accordingly, primary subjects will be discussed in this first course, and more advanced material will come later.

This is a working course in which each person registered will be expected to apply himself diligently and to acquire as much as possible from the lectures and from the demonstrations to be given. It may be inconvenient for some to listen hour after hour to lectures, especially when they have not been accustomed to this, but there will be intermissions, and the changes in the subjects should overcome most difficulties of this nature.

The number of courses of instruction is expected to be three before a Certificate of Qualification is granted. The later courses will be more specialized and it may be desirable to break them up according to the kinds of works being done by each operator. Laboratory may be desired by some more than than by others.

It should be made clear that this course is not given in preparation for a licencing system, although some such are in effect in the United States. These courses are intended to provide a qualification which will be recognized throughout this Province. The successful candidate, at the conclusion of the full set, will be given a certificate indicating that he is qualified in his field. Each person attending the courses should have had some experience in sewage plant operation. If he has been in this field for some time there will, no doubt, be a repetition of some information which is familiar to him. This must not be considered as objectionable, but rather as placing emphasis on it. It is hoped that cricisms and recommendations will come from the group, and that there can be discussions of the various subjects following their presentation. Legislation and procedures in effect in Ontario will be stressed.

SUBJECTS OF THE COURSE

You will see that the timetable covers a wide variety of subjects. Emphasis is put on background information and on operating problems. Elementary laboratory tests are included, and as the courses advance there will be more of that. An examination will follow the completion of each course at the end of the week. The objective is not merely to teach the operator certain subjects but rather to stimulate his interest in his work, and to emphasize his importance in the overall scheme. The Commission is cognizant of the very important part which the operator plays in stream sanitation.

FUTURE COURSES AND EXAMINATION

The present plans are to have future courses at about six month intervals. Thus, a person starting this one would gradually advance to the next two. In addition, these primary courses will be repeated for those who have not been able to attend this one. Each municipality sending an operator is making an investment, and it is hoped that the returns will well justify the time and effort expended.

CERTIFICATION OF OPERATORS

In days of competition and technical advances it is obvious that the operator who has obtained adequate training should be recognized in some tangible manner. Certification appears to be the best procedure. It is hoped that the certificates to be issued by the Commission to those obtaining qualification will be recognized throughout the municipalities of this Province and that they will become increasingly important, regardless of where the operator may work. This is in keeping with a plan for water works operators and for others in the field covered by the OWRC.

READING AND SELF-TRAINING

No course of instruction can complete the education of an operator. This course is intended to act as a start and a stimulus to greater knowledge. It is thus hoped that the operator will follow conscientiously on the instruction given here, and will take advantage of reading from text books, magazines, and other publications. Continuous study is imperative to keep up with the rapid advances taking place in these techniques today.

THE FOLLOW-UP PROGRAMMES

The foregoing will indicate the objectives of this training and the proposal for certification. It is also hoped that this information may be supplemented by further action to be taken by the OWRC and by the operators themselves. Some of these actions may be listed, as follows:

The Commission expects to publish, as soon as possible, the lectures given at this course. This material will serve as a reference, and each operator will be supplied with a copy which he is asked to keep on file and to study in full detail.

The operator can also acquire valuable information through an exchange of experience with others. The number of sewage treatment plants in the Province is growing steadily, and greater information is being accumulated on operating problems. A conference of this kind aids greatly in an exchange of information, apart from anything that is given in the lectures and in the laboratory work. Organizations which provide information for the operator can also be useful to him as are periodic meetings arranged among the operators themselves. Membership in an Organization such as the Canadian Institute on Pollution Control will prove another valuable aid to every plant operator.

It is desirable that there be a set of books and magazines at each sewage treatment plant. Many are published today, and if a wise selection is made they can prove to be exceedingly valuable to the operator in his daily problems.

The Commission publishes, on a fairly regular basis, research bulletins and other information which serves to keep the operator abreast of new developments, and there is also the contact in the field between the staff of the Commission and the operators as inspections are made of the plants.

One of the main features about any course of instruction is the incentive it creates in the minds of the students to acquire greater knowledge. This will rest with the individual. This course must assist him towards attaining this objective.

THE ROLE OF THE SEWAGE WORKS OPERATOR IN THE FIELD OF PUBLIC HEALTH

H. Browne
Supervisor of Sewage Works
Division of Sanitary Engineering

The proper operation of a sewage treatment plant is important in protecting the public health of any community. It is recognized that untreated sewage discharged to a stream can carry with it dangerous bacteria and viruses, which, if taken into a public water supply, may result in sickness or even in death to those who consume the water. It is essential, therefore, that operators of sewage treatment plants become acquainted with problems that they must meet in their every day work so that they may run plants to the best of their ability. There is, consequently, some responsibility in the protection of the public health of the community in the operation of a sewage disposal plant.

OPERATION OF SEWAGE PLANT BECOMING MORE DIFFICULT

There are many factors that make the operation of a sewage disposal plant more difficult and perplexing with each passing year as residential and industrial growth mushrooms, distances between sewage outfalls and water intakes become less and less and many complex, new and persistent types of pollutants complicate the situation. The discovery of new enteric viruses present in human wastes, and against which routine chlorination treatment has little effect, has caused additional concern. There is much to learn about new and changing problems in the field of sewage treatment that make the task of the operator increasingly more difficult.

OPERATION OF SEWAGE PLANT NOT AN EASY TASK

The operation of a sewage disposal plant with its many complications is, therefore, not an easy task. There should be a greater appreciation by the general public and by elected representatives that there are no complete answers to many of the problems that an operator of a sewage treatment plant meets in his work from day to day. Everyone has heard the assurances of proponents of sewage plants that there will be no offensive odours in the atmosphere in the vicinity of a new sewage plant. Later, the operator is confronted with conditions such as gross overloading by residential growth and shock industrial loads, heavy infiltration on the sewerage system, foaming synthetic organics, inadequate receiving streams, improper design, unsuitable equipment, and a variety of other perplexing problems. It is, therefore, practically an impossibility that there will always be an odour-free atmosphere in the vicinity of a sewage plant. There should be a greater understanding of that fact, and also that a sewage plant operator works under trying circumstances in endeavouring to provide an assurance that is not based on reality.

PLANT SHOULD BE OPERATED TO BEST OF ABILITY

It has been indicated that the sewage works operator has an important role in the protection of public health. It is his responsibility to operate the plant to minimize the pollution that reaches the receiving stream and the hazards to any water supplies or swimming areas. The condition of the receiving stream, and the possibility of adding contamination to it, should, therefore, be a foremost consideration in the operation of any sewage treatment plant. The operator should acquire sufficient training to meet problems that confront him from day to day. It must be recognized that there are certain problems that may require sewer or plant changes or extensions that are beyond the ability of the operator to provide. It is essential that these changes or extensions be provided before the operator can run the plant efficiently. The responsibility for the proper operation of a sewage plant is not the operator's alone.

EMPLOYEE TRAINING FOR SEWAGE WORKS OPERATION

A well trained operator is definitely an asset if a sewage works plant is to function properly, but a conclusion that all operators without formal training are unable to operate treatment plants is basically wrong. Many operators through adequate initial instruction from their fellow operators and by studying the literature become quite able to operate their own or similar plants. It must be recognized, nevertheless, that the acquisition of training is of considerable value in operating any sewage plant with its myriad of problems.

TYPES OF OPERATORS REQUIRED IN LARGE AND SMALL PLANTS

The operation of a large sewage plant requires a person in charge that has a knowledge of the mechanical, biological and chemical aspects of the treatment. As a result, one often finds an engineer supervising the mechanical details and a chemical engineer or bacteriologist in charge of the treatment. It is essential in the larger plants that both types of knowledge be available. In the smaller plants there is the need for an operator with mechanical ability who can acquire through reading and training courses the knowledge that is necessary to meet the problems that accrue. That is the basic reason for the establishment of the sewage operators' training course.

TRAINING OPPORTUNITIES HAVE BEEN LIMITED

It is true that the opportunity for training for a sewage works operator has been more limited than for an operator in the water works field. Most sewage works operators have had to depend on correspondence schools or on reading to further their training. It is hoped, therefore, that the OWRC at this course and in the future may be able to provide some measure of training at its schools. This will permit a sewage works operator to acquire knowledge on problems that may arise and also the methods employed and the agencies available to him in correcting the conditions that do materialize.

MAIN ESSENTIAL TO GOOD OPERATION

The main essential to good operation is that the operator of a sewage plant have some basic mechanical or technical training so that he can operate the plant to the best of his ability. The operator must also have the facilities to do his job and understand the limitations of his plant. He should have an appreciation of the fact that bacteria or viruses dangerous to humans can readily go through the sewage plant and that precautions are required if there is any swimming area or water supply that may be endangered in the vicinity of the sewage plant outfall.

SHOULD OPERATE PLANTS TO MAINTAIN OBJECTIVES OF WATER QUALITY IN RECEIVING STREAM

It must be recognized that sewage treatment does not completely disinfect the effluent that is discharged from a sewage plant. Therefore, an operator cannot hope to produce an effluent that will not constitute some hazard to the receiving stream. All he can do is to operate the plant to maintain the stream to a standard that will suit the conditions in the area. Often these standards have not been set but are designated as objectives rather than precise standards. The objectives in Ontario require that the treatment be sufficient for adequate removal or reduction of solids, bacteria and chemical constituents which may interfere unreasonably with the use of the receiving water for domestic water supply, bathing, and fish and wild life. It is considered that adequate protection for these waters will be provided if the coliform M.P.N. median value does not exceed 2,400 per 100 ml. at any point in the waters following initial dilution and if the suspended solids and 5-day BOD of the discharge are not both in excess of 15 ppm. It must be recognized that this will require secondary treatment in order to achieve these objectives. It must be agreed that in certain specific instances influenced by local conditions that even these objectives must be exceeded, if the receiving stream is inadequate in flow or if there is any immediate danger to a swimming area or water works intake. The provision of effluent filters and of chlorination may then be required to assure a safer effluent. Disinfection of effluent is arbitrarily defined

as the addition of sufficient chlorine so that a chlorine residual of 0.5 ppm is present 15 minutes after the chlorine is applied. The point of chlorine application must be such that the entire flow of sewage can be chlorinated and be held for 15 minutes before discharge to the receiving stream. On the other hand, there are many plants that have adequate diluting water in the receiving stream and have, therefore, been designed for primary treatment. At such plants the objectives for receiving stream water permit higher suspended solids and 5-day BOD contents. Chlorination may or may not be required, dependent on the danger to water supplies or swimming areas below the outfall.

OPERATOR SHOULD KNOW OBJECTIVES FOR RECEIVING STREAM WATER

The sewage works operator should then ascertain the objectives that he must maintain to keep the receiving stream in a suitable condition. These objectives vary because of many factors such as, the type of plant, the location of nearby water works plants or swimming areas, large industries in the area using quantities of process water, beach areas that must be protected, algae growths and other conditions. Studies are necessary to determine the degree of treatment that is required to maintain the objectives for water quality in the receiving stream. Every effort should be made to operate the plant so that these objectives can be maintained.

BY-PASSING OF SEWAGE SHOULD BE AVOIDED

It is basic that by-passing of sewage from a plant should be kept to a minimum. It is recognized that at the time of storms the excess flow beyond two and one-half times the dry weather flow will be by-passed and that on occasion the operator is confronted with a maintenance problem that will require by-passing of sewage. However, deliberate by-passing because of problems in operation should be avoided if at all possible. Every effort should be made to solve the problem before resorting to by-passing. In many cases the correction may require the aid of outside authorities to find the solution. Such aid should be sought. In other

problems it may require the provision of additional facilities either on the sewerage system or at the plant. The attention of local officials responsible for providing such improvements should be drawn to the need for their installation.

BY-PASSING OF SEWAGE IN WINTER OR AT RUN-OFF PERIODS

A sewage plant operator should appreciate that sewage solids deposited on the bottom of the stream during winter may exert an oxygen requirement for a long time. Discharges of sludge in winter and at spring run-off periods may solve several problems at the plant but may cause adverse conditions in the receiving stream long after the by-passing has taken place. The plant should, therefore, be operated so that no heavy by-passing of sewage or discharge of sludge is made at times that are not suitable for such discharges. Such by-passing can definitely affect the receiving stream to a marked degree although it may not be evident at the time.

SUPERVISION OF CHLORINATION AT CERTAIN TIMES IN THE YEAR

A major protection to the public health of any community is proper chlorination of the sewage plant effluent. If chlorination has been installed in a plant, it has been required as an added safeguard. Therefore, if the operator neglects to maintain a proper residual he is reducing the protection that the treatment provides. It is true that research will have to find the answer and assess the public health significance of the growing array of new-type enteric viruses and synthetic organics that do not break down like natural organics. The operator can only wait for research to determine the answers to such complex questions. However, he has the answer to the reduction of well known diseases such as typhoid, paratyphoid and dysentery by effective chlorination. He can at least protect the public from such diseases by operating his plant and, in particular, the chlorination equipment to the correct standards. The need for chlorination in off-swimming months is one that should be decided on the basis of the conditions in the area. If the treatment is required only to protect a swimming area then chlorination can be suspended. If it is required to

protect a water supply it should be continued at all times. It is generally recognized that the organism which causes typhoid fever lives longer in cold water than in warm water. Consequently, it is apparent that chlorination should be continued to protect the water supply below the outfall.

SIGNIFICANCE OF FISH KILL

It is true that the fish and wild life of a stream are not important from the standpoint of public health. Yet, there is nothing outside of offensive odours from a sewage plant that will raise the ire of the general public more than a fish kill in the receiving stream. It is gratifying to learn, therefore, that effluents from sewage plants rarely cause fish kills. According to the first nation-wide survey made in the United States, effluents from sewage plants accounted for only eight per cent of the total fish kills. Agricultural poisons from run-off of fertilized lands accounted for forty per cent of the total, and industrial wastes for thirty-one per cent. In all probability, if a fish kill takes place, it is not caused by the sewage plant effluent unless it contains a toxic industrial constituent or the oxygen in the receiving stream is depleted by a heavy discharge of sludge or sewage at one time. There is more danger from independent industrial waste discharges and from fertilizers used on the land.

SIGNIFICANCE OF PROLIFIC ALGAE GROWTHS

The existence of prolific growths of algae in the receiving streams has caused concern in recent years. These growths may or may not be located in the vicinity of sewage works outfalls. If they are there is little doubt that the sewage effluent provides some measure of fertilization for the growths. An improvement in the treatment at the sewage plant will not reduce these growths; in fact, it may increase them. The answer to the problems, therefore, does not rest with the operator. It will come in the research being carried out on improved sewage treatment and the use of algicides to eliminate the algae. Some progress is being made in this research.

SIGNIFICANCE OF NEW SYNTHETIC CONTAMINANTS

Sewage plants now receive an ever increasing amount of new-type synthetic chemical contaminants. These synthetic organics do not break down but persist over long periods of time. They are not removed either by sewage treatment or by normal water purification practices. They often cause concern and even consternation below sewage plant outfalls. Once again the answer to the problem does not lie with the operator of the plant. There is much to learn about the behaviour of these new contaminants and their long range subtle effects on public health, on aquatic growths and on municipal water supplies. Research must find the answer for these synthetic pollutants just as for prolific algae growths before the operator can take definite action to eliminate them.

OPERATOR SHOULD HAVE FACILITIES TO DO WORK PROPERLY

It is important that the sewage works operator have the facilities to operate the plant properly if he is to provide the supervision that is required. In many municipalities the design of a sewage plant is cheapened due to economic factors so that facilities to meet each condition are not available. Yet the general public is unaware of this condition and expects the operator to be able to turn out a good effluent from the plant and to keep the area free from odours at all times. It if true that the sewage works operator will usually give careful responsible supervision, but often he will find conditions created that are beyond his, or anyone else's, capability to correct because of inadequacy in plant equipment or design.

CONDITION THAT OVER TAX A SEWAGE PLANT

Conditions that can readily over tax the design, capacity and equipment of a plant are heavy infiltration on the sewerage system, septic conditions in the sewers or at the plant, heavy or shock industrial loads or overloading of the hydraulic designed capacity of the plant. If these conditions exist the operator should make them known to the inspecting authorities and to the responsible municipal

officials so as to achieve an improvement. If the operator does not receive such assistance he cannot provide proper operation for the plant.

LOCATION OF PLANT IS IMPORTANT IN TYPE OF OPERATION PROVIDED

An operator should evaluate the location of the sewage plant to points that require protection such as swimming areas, bathing beaches and water supplies. He should appreciate the public health significance if heavy contamination should reach those points. While careful operation is desired at every plant it is doubly required at plants that are potential dangers to the public.

PROTECTION OF THE OPERATOR'S HEALTH

There is one last point that is important in the protection of public health by the sewage plant operator. It is the protection of his own personal health. An operator must remember always that the flow through his plant may contain bacterial and virus infections that may cause him illness and even death. There is the danger from cuts that may result in tetanus, the hazard of drowning particularly when ice covers the walk-ways in winter, the threat of explosion and asphxiation from poisonous accumulations of gas. The operation of a sewage plant is a hazardous occupation not an easy one. An operator should, therefore, take every precaution to avoid infection and should obey all safety rules to protect himself against explosions, drowning and asphyxiation. Be interested in public health protection, but do not forget your own health.

SUMMARY

The role of the sewage works operator in the field of public health can be summarized as follows:

(1) He should obtain training so as to operate the plant to the best of his ability and to be aware of the limitations of the plant's design and equipment.

(2) He should bring to the attention of the responsible authorities the limitations of his plant to meet problems so that they can plan and budget for improvements.

(3) He should know the standards that he should reach at his plant to maintain the objectives for water quality in the receiving stream.

(4) He should avoid by-passing of sewage or discharge of sludge to the receiving stream, whenever possible.

(5) He should maintain the chlorine residual in the effluent at all times when such treatment is required.

(6) He should learn the location of the swimming areas and water supplies in the area so that he can provide suitable protection to these areas or supplies.

(7) He should take every precaution to protect his own health and welfare. The knowledge of safety is essential, therefore, for every operator.

(8) He should realize that research still has to find the answer for many of the problems that cause difficulties in a sewage plant from day to day.

(9) He should endeavour to establish and maintain good public relations.

BASIC MATHEMATICS

J. Stasiuk, P. Eng.

Engineer
Division of Sanitary Engineering

An operator of a wastewater treatment plant should routinely evaluate the efficiency of the plant and of the individual units. In most activated sludge plants routine laboratory tests are performed daily to ensure that the plant is effectively tuned to operate under optimum conditions. The analyses determined in the laboratory will assist the operator in deciding whether any adjustments are necessary to the treatment units to achieve a high degree of efficiency of operation.

This necessitates that the operator be able to apply the laboratory data made available to him. It is essential that he has a good sound knowledge of basic mathematics to fully understand the significance of the results.

The object of this presentation is to help the student recollect some of the mathematics he learned at school and be able to apply it to the sewage treatment process. In addition, it will prepare the student to appreciate more fully the material to be presented in subsequent lectures of this course.

ARITHMETIC

Addition

The basic rule when adding numbers that have no decimals and which do not have the same number of digits (a single figure like 4, 7, 6, etc.) is to arrange them starting from the right hand side.

If the numbers contain units such as inches, feet, yards or pounds, etc., all the numbers must be changed to a similar unit before attempting the addition.

Example: add 4 inches, 3014 inches, 68 inches and 11,762 inches

```
    4 inches
 3014 inches
   68 inches
11762 inches
-----
   18
  13
  7
 4
1
-----
14848 inches
```

Subtraction

Subtraction is literally the inverse of addition but the arrangement of numbers is similar when preparing to carry out the subtraction.

Example: subtract 7413 from 621

```
  7413
-  621
  ----
  6792
```

You can check your subtraction by adding the answer to the number being subtracted and the resulting answer should be the original or first number.

```
  6792
+  621
  ----
  7413 checks with the first number above.
```

You should develop a habit of mentally checking all your subtractions.

Example: subtract 8572 feet from 10,681 feet

```
 10,681 feet
- 8,572 feet
  2,109 feet  (answer)
 10,681 feet  (check)
```

Multiplication

Multiplication is essentially the process of adding a certain number a given number of times.

$$3 + 3 + 3 + 3 + 3 + 3 + 3 = 3 \times 7 = 21$$

It would be helpful at this stage to be thoroughly familiar with your multiplication table. If you are not, you should spend some time reviewing it.

The mathematical terminology of multiplication is:

$$\begin{array}{ccccc} \text{multiplicand} & \times & \text{multiplier} & = & \text{product} \\ 85 & \times & 31 & = & 2635 \end{array}$$

Example:

$$\begin{array}{r} 6231 \\ \times\ 42 \\ \hline 12462 \\ 24924 \\ \hline 261702 \end{array}$$

When multiplying two numbers, the units do not have to be identical. However, units as well as numbers have to be multiplied.

Example:

1. 4 yards x 8 yards = 32 (yds. x yds.) = 32 yds^2

2. 8 acres x 2 inches = 16 acre-inches

3. It takes 6 men to complete a job in 8 hours. Therefore we can say it took (6 men x 8 hours) 48 man-hours to do the work.

Two points you should bear in mind are:

1. (any number) x 1 = the number

2. (any number) x 0 = 0

Example: 432 x 1 = 432

407 x 0 = 0

Division

Division is the process of determining how many times one number is contained in another.

The mathematical notation is:

```
         quotient
divisor/dividend
```

4 is contained in 8, 2 times

```
    2
4 / 8
```

Example: divide 261,702 by 42

This may also be expressed as $\frac{261,702}{42}$

or 261,702 ÷ 42

```
   6231
42/261702
   252xxx
    97
    84
    130
    126
      42
      42
       0
```

The quotient (answer) is 6,231. In this case the divisor is contained in the dividend exactly 6,231 times. However, there could be a remainder as the following problem exemplifies.

Example: divide 8,472 by 76

```
   111
76/8472
   76xx
    87
    76
    112
     76
     36
```

answer: 111, remainder 36

The division can be checked by multiplying the divisor by the quotient and adding the remainder. This figure should check with the dividend if the computation was carried out correctly.

The following example illustrates a check of the above computation:

$$\begin{array}{r} 111 \\ \times\ 76 \\ \hline 666 \\ 777 \\ \hline 8436 \\ +\ 36 \\ \hline 8472 \end{array}$$

This answer checks with the original dividend therefore the answer is correct.

FRACTIONS

A fraction is an expression of one or more parts of a unit or a whole number. The various rules in dealing with the different operations using fractions namely, addition, subtraction, multiplication are presented below. The upper number of a fraction is known as the numerator and the lower one a denominator.

That is: $\frac{\text{numerator}}{\text{denominator}}$

Cancellation

A useful principle to bear in mind regarding fractions is that the value of a fraction is not altered if the numerator and denominator are multiplied or divided by the same number. This principle is known as the principle of cancellation.

Example: $\frac{2}{3} = \frac{2 \times 3}{3 \times 3} = \frac{6}{9}$

or $\frac{6}{9} = \frac{6 \div 3}{9 \div 3} = \frac{2}{3}$

However, the same principle does not apply if the same number is added to or subtracted from the numerator and denominator of a fraction.

$$\frac{3}{4} \text{ does not equal } (\neq) \ \frac{3+2}{4+2} = \frac{5}{6}$$

$$\text{or } \ \frac{3}{4} \neq \frac{3-1}{4-1} = \frac{2}{3}$$

The concept of these fundamentals is one of the most useful tools when working with fractions.

Addition and Subtraction

When fractions are to be added or subtracted it is necessary that the denominators of all fractions be identical. If they are not, we utilize the principles illustrated above. That is, we suitably change the numbers of the fraction without actually altering the value of the fraction and complete the required computation.

The least common denominator is the lowest number that both denominators will divide into with nothing left over. In the case of the addition or subtraction of fractions, this is the number we try to obtain in all denominators. We then perform the required calculation as indicated in the problem using the numerators and express the resultant numerator over the common denominator.

<u>Example:</u> calculate $\frac{1}{2} + \frac{3}{4}$

The common denominator (the smallest number 2 and 4 divide into with no remainder) is 4. Express both fractions, without changing its value, having a denominator of 4.

$$\frac{1 \times 2}{2 \times 2} + \frac{3}{4} = \frac{2}{4} + \frac{3}{4}$$

Now complete the addition of the numerators and express the resultant numerator over the common denominator.

$$\frac{2}{4} + \frac{3}{4} = \frac{5}{4}$$

Example: calculate $\frac{1}{3} + \frac{3}{5} - \frac{1}{10}$

The common denominator is 30 because 3, 5 and 10 all divide into it with no remainder.

$$\frac{1 \times 10}{3 \times 10} + \frac{3 \times 6}{5 \times 6} - \frac{1 \times 3}{10 \times 3}$$

$$\frac{10}{30} + \frac{18}{30} - \frac{3}{30} = \frac{28}{30} - \frac{3}{30} = \frac{25}{30}$$

Fractions are generally reduced to their simplest form.

$$\frac{25 \div 5}{30 \div 5} = \frac{5}{6}$$

In some examples a whole number will be associated with a fraction (mixed fraction i.e. 4 7/8) and before any calculations are executed this expression should be changed to the fractional form (improper fraction i.e. $\frac{39}{8}$).

To change a mixed fraction to an improper fraction:

1. multiply the denominator by the whole number and add the result to the numerator.

2. express as an improper fraction by taking the result obtained in (1) as the numerator and the original denominator as the final denominator.

Example: express $3\frac{5}{8}$ as an improper fraction

$$\frac{(3 \times 8) + 5}{8} = \frac{29}{8}$$

Multiplication

The procedure for multiplying fractions is to multiply the numerators for the new numerator and the denominators for the new denominator.

Example: 1. compute $\frac{3}{4} \times \frac{5}{8}$

$$\frac{3}{4} \times \frac{5}{8} = \frac{15}{32}$$

2. $1\frac{3}{5} \times 2\frac{1}{3}$

$$\frac{(5 \times 1) + 3}{5} \times \frac{(3 \times 2) + 1}{3} = \frac{8}{5} \times \frac{7}{3}$$

$$= \frac{56}{15} = 56 \div 15 = 3\frac{11}{15}$$

Division

The procedure to follow when dividing fractions is to invert the divisor and multiply as described above.

Example: 1. invert the following numbers $\frac{3}{5}$, $\frac{1}{5}$ and 8

$\frac{3}{5}$ answer $\frac{5}{3}$

$\frac{1}{5}$ answer $\frac{5}{1} = 5$

8 answer $\frac{1}{8}$

2. $\frac{3}{5} \div \frac{4}{3}$

invert the divisor, then multiply

$$\frac{3}{5} \times \frac{3}{4} = \frac{9}{20}$$

3. $2\frac{1}{2} \div 1\frac{6}{7}$

$$= \frac{5}{2} \div \frac{13}{7} = \frac{5}{2} \times \frac{7}{13}$$

$$= \frac{35}{26} = 11\frac{11}{26}$$

Ratio

Ratio is a term which will be referred to in future lectures of this course. It is defined as a mathematical statement of the comparison of two quantities having the same units and expressed in the form of a simple fraction. For example, if plant A has a capacity of 6 mgd and plant B a capacity of 2 mgd, the ratio of the capacities of plant A to plant B is

$$\frac{6 \text{ mgd}}{2 \text{ mgd}} = \frac{3}{1} \text{ or } 3:1$$

Example: If a 1 mgd primary plant costs $300,000.00 and a 1 mgd conventional activated sludge plant costs $500,000.00 what is the ratio of costs?

$$\frac{\text{cost of primary plant}}{\text{cost of activated sludge plant}} = \frac{300,000}{500,000} = \frac{3}{5} \text{ or } 3:5$$

DECIMALS

A fraction could also be expressed in the decimal form. Decimals express fractions in multiples of 10, that is; tenths ($\frac{1}{10} = 0.1$), hundredths ($\frac{1}{100} = 0.01$) and thousandths ($\frac{1}{1000} = 0.001$) etc.

Example: $\frac{2}{10}$ is 0.2

$\frac{2}{100}$ is 0.02

$\frac{2}{1000}$ is 0.002

One of the most common uses of decimals is evidenced in the Canadian monetary system. (50 cents is 0.50 of a dollar, 37 cents is $\frac{37}{100}$ of a dollar or \$0.37).

The term "decimal places" designates the number of figures to the right of a decimal point in a number. For example, 0.0321 is expressed to four decimal places. We may also have numbers in front of the decimal point as in 437.672. A good practice to follow when there are no numbers to the left of the decimal point is to represent this case by placing a zero immediately in front of the decimal point i.e. 0.863.

Adding and Subtracting Decimal Fractions

When arranging decimal fractions which are to be subtracted or added place the numbers in such a way that all the decimal points are in the same vertical column. If a number is shown with no decimal point, it is understood that a decimal point may be placed just to the right of the last figure in that number. That is, 383 is the same as 383.00. Annexing zeros after the last number of a decimal does not alter its value.

37.47 is the same as 37.4700
838 is the same as 838.000

Example: 1. add 431, 67.891, 24.37, 4, 0.010 and 3.125

$$\begin{array}{r} 431.000 \\ 67.891 \\ 24.370 \\ 4.000 \\ 0.010 \\ 3.125 \\ \hline 530.396 \end{array}$$

2. subtract 624.315 from 38.24

```
 624.315
- 38.240
 586.075  answer
 624.315  check
```

Multiplication of Decimal Fractions

The multiplication is performed in the usual manner and the answer will contain as many decimal places as the sum of decimal places in the multiplicand and multiplier (the numbers just multiplied).

Example: perform the multiplication 31.802 x 6.51

```
   31.802
   x 6.51   - a total of five decimal places
    31802     in the numbers being multiplied
  159010
 190812
 20703102   - a total of five decimal places in
              the product
```

Division of Decimal Fractions

When dividing a number containing a decimal fraction by another decimal fraction the following procedure applies.

1. Count the number of decimal places the decimal has to be moved to the right to make the divisor a whole number.

2. Move the decimal point in the dividend the number of decimal points to the right (adding zeros if necessary) as in (1). Essentially, the numerator and denominator have been multiplied by the same number, therefore, not changing the value of the fraction.

3. Divide keeping the decimal point in the quotient directly above the decimal point in the dividend and the units above the corresponding units of the dividend.

<u>Example:</u> divide 11.36 by 3.2

In accordance with the rules above:

1. 3.2 becomes 32 (a whole number). We have multiplied it by 10.

2. We also move the decimal one decimal point to the right in the dividend so that, 11.36 becomes 113.6. We have also multiplied it by 10.

3.
```
       3.55          check   3.55
   32/113.60                  x 32
       96                     7 10
       17 6                 106 5
       16 0                 113.60
        1 6 0
        1 6 0
            0
```

checks with original dividend therefore the answer is correct.

PERCENT

Percent is a useful mathematical concept in any field since it gives one a clear comparison of efficiencies, loadings, etc. Literally "per" means "divided by" and "cent" means "hundred". Therefore, the whole is divided into 100 equal parts and the percent quoted is an expression of the <u>part</u> of the <u>entire portion</u> with which you are concerned. That is, 100% is the entire portion, 50% is one-half of the entire portion, 25% is one-quarter of the entire portion, 10% is one-tenth of the entire portion, etc.

<u>Example:</u> 1. What is 20% of 300

20% expressed as a fraction is $\frac{20}{100}$

Therefore 20% is $\frac{20}{100}$ or 0.20 of 300

$0.20 \times 300 = 60$

2. If a ton of sludge contains 90% water, what is the weight of water in the mixture.

one ton = 2,000 lb.

$0.90 \times 2000 = \frac{90}{100} \times 2000 = 1800$ lb. of water

EXPONENTIAL NUMBERS

For ease of expression numbers are often stated in an exponential form. This is especially the case for very large or small numbers. It is the technique of stating a number or performing a mathematical operation with the number to the power of 10:

Notation

$10^0 = 1$	$10^{-1} = \frac{1}{10}$	$= 0.10$
$10^1 = 10$	$10^{-2} = \frac{1}{100}$	$= 0.01$
$10^2 = 100$	$10^{-3} = \frac{1}{1000}$	$= 0.001$
$10^3 = 1,000$	$10^{-4} = \frac{1}{10000}$	$= 0.0001$
$10^4 = 10,000$	$10^{-5} = \frac{1}{100000}$	$= 0.00001$
$10^5 = 100,000$	$10^{-6} = \frac{1}{1000000}$	$= 0.000001$
$10^6 = 1,000,000$	$10^{-7} = \frac{1}{10000000}$	$= 0.0000001$

Rule 1. Any number to the power zero = 1

$$10^0 = 1$$

$$2^0 = 1$$

Rule 2. When numbers to a power of 10 are multiplied, the numbers are multiplied and the <u>powers</u> or exponents are added for the final answer.

$$3 \times 10^2 \times 2 \times 10^5 = 3 \times 2 \times 10^{5+2} = 6 \times 10^7$$

Rule 3. When two numbers to the power of 10 are divided, the numbers are divided and the exponent of the divisor is subtracted from the exponent of the dividend for the final answer.

$$9 \times 10^7 \div 3 \times 10^4$$

$$= \frac{9}{3} \times 10^{7-4} = 3 \times 10^3$$

Example: 1. express in the exponential form:

(a) $432 = 4.32 \times 100 = 4.32 \times 10^2$

(b) $0.0461 = \frac{4.61}{100} = 4.61 \times 10^{-2}$

(c) $2{,}000{,}000 = 2 \times 1{,}000{,}000 = 2 \times 10^6$

2. perform the indicated mathematical operation:

(a) $3 \times 10^4 \times 7 \times 10^5 = (3 \times 7) 10^{(4+5)} = 21 \times 10^9$

(b) $6.7 \times 10^{-2} \times 3.4 \times 10^7 = (6.7 \times 3.4) 10^{(-2+7)}$
$= 22.78 \times 10^5$

(c) $4 \times 10^5 \div 2 \times 10^3 = \frac{4}{2} \times 10^{(5-3)} = 2 \times 10^2$

(d) $7.5 \times 10^7 \div 2.5 \times 10^4 = \frac{7.5}{2.5} \times 10^{(7-4)} = 3 \times 10^3$

UNITS

A unit is the term of reference in a mathematical statement i.e. in the expression 3 feet the unit is feet, in 14 yards the unit is yards. It describes the form of measurement being used in the expression or computation.

The most common forms of measurement are the English and metric systems. The U.S. system is identical to the English one except for liquid measure. All of these systems are used in Canada. Consequently, we must be able to readily convert from one system to another.

Rule 1. Concrete numbers associated with a physical unit can be added or subtracted only when they all possess the same physical unit.

3 feet + 2 yards = 3 feet + 6 feet = 9 feet

Rule 2. Concrete numbers, whether they have the same unit or not, can be multiplied or divided; however, a new unit is created since the units are subject to cancellation or multiplication.

<u>Example:</u> 1. solve

$$6 \text{ ft.} \times 3 \text{ ft.} = 18(\text{ft.} \times \text{ft.}) = 18 \text{ ft.}^2$$

2. A man drives 120 miles in 2 hours. At what speed is he driving?

$$\frac{120 \text{ miles}}{2 \text{ hours}} = 60 \text{ miles/hour}$$

1 hour = 60 minutes

$$3 \text{ hours } \frac{(60 \text{ minutes})}{\text{hour}} = 180 \text{ minutes}$$

Note how the units are cancelled.

A conversion table is appended to this lecture to enable you to convert to the desirable unit system.

PARTS PER MILLION

The term parts per million is used so extensively in the water and sewage works field to express analytical laboratory results that a complete section is devoted to its study.

Parts per million is a weight-to-weight ratio. It is used because of the high water dilution composing the sewage wastes. Basically, it is the weight of a substance, say in pounds, in one million pounds of the solvent.

If we have 10 lb. of chlorine contained in 1,000,000 lb. of water, the concentration of chlorine in water may be expressed as follows:

$$\frac{10 \text{ lb.}}{1,000,000 \text{ lb.}} = 10 \text{ ppm}$$

An important conversion factor to remember is:

$$1 \text{ ppm} = \frac{1 \text{ miligram}}{\text{litre}} = 1 \text{ mg/l}$$

Example: If we have a concentration of suspended solids (SS) of 15 ppm in a sewage effluent, approximately how many pounds of solids do we have in 100,000 gal. of sewage?

1 gal. of water = 10 lb.

It can be assumed that 1 gal. of sewage = 10 lb.

$$1 \text{ ppm} = \frac{1 \text{ lb.}}{100,000 \text{ gal.}}$$

$$\text{Concentration of solids} = 15 \text{ ppm} = \frac{15 \text{ lb.}}{100,000 \text{ gal.}}$$

Therefore, we have 15 lb. of suspended solids for every 100,000 gallons of sewage.

CONCLUSION

The operator should become very familiar with the mathematics just covered. It may be necessary to refer to mathematics texts for a more complete coverage. Nevertheless, in subsequent lectures of mathematics if one is to proceed at an expected rate of progress it must be assumed that he is thoroughly capable of solving mathematical problems covering the topics discussed in this lecture.

One final word of instruction is that when the operator is solving a mathematical problem he should mentally know in what range of magnitude to expect the answer. A common error is misplacing the decimal point in the final solution. When the

problem has been solved, ask yourself: Does the answer make sense? It may save you from some embarrasing moments later when the answer is being quoted to your superiors.

In future lectures algebra and geometry will be discussed in relation to sewage treatment. Operators should prepare themselves for these lectures by reviewing these branches of mathematics prior to the next course.

CONVERSION UNITS

Multiply	By	To Obtain
ACRES	160	Square rods
Acres	4840	Square yards
Acres	43.560	Square feet
ACRES INCHES	27,154	Gallons
ACRES INCH/HR	452	GPM
ATMOSPHERES (STD.) 760 MM of Mercury at 32°F	14.696	Lbs./sq. inch
ATMOSPHERES	76.0	Cms. of mercury
Atmospheres	29.92	Inches of mercury
Atmospheres	33.90	Feet of water
Atmospheres	1.0333	Kgs./sq. cm.
Atmospheres	14.70	Lbs./sq inch
Atmospheres	1.058	Tons/sq. ft.
BARRELS-OIL	42	Gallons-Oil
BARRELS (Beer)	31.5	Gallons
(Wine)	31.0	Gallons
BRIT. THERM. UNITS	0.2520	Kilogram-calories
Brit. Therm. Units	777.5	Foot-lbs.
Brit. Therm. Units	3.927×10^{-4}	Horse-power-hrs.
Brit. Therm. Units	107.5	Kilogram-meters
Brit. Therm. Units	2.928×10^{-4}	Kilowatt-hrs.
B.T.U./MIN	12.96	Foot-lbs./sec.
B.T.U./min	0.02356	Horse-power
B.T.U./min	0.01757	Kilowatts
B.T.U./min	17.57	Watts
CENTARES (CENTIARES)	1	Square meters
CENTIGRAMS	0.01	Grams
CENTILETERS	0.01	Liters
CENTIMETERS	0.3937	Inches
Centimeters	0.03280	Feet
Centimeters	0.01	Meters
Centimeters	10	Millimeters
CENTIMTRS. OF MERC.	0.01316	Atmospheres
Centimtrs. of merc.	0.4461	Feet of water
Centimtrs. of merc.	136.0	Kgs./sq. meter
Centimtrs. of merc.	27.85	Lbs./sq. ft.
Centimtrs. of merc.	0.1934	Lbs./sq. inch
CENTIMTRS./SECOND	1.969	Feet/min.
Centimtrs./second	0.03281	Feet/sec.
Centimtrs./second	0.036	Kilometers/hr.
Centimtrs./second	0.6	Meters/min.
Centimtrs./second	0.02237	Miles/hr.
Centimtrs./second	3.728×10^{-4}	Miles/min.
CMS./SEC./SEC	0.03281	Feet/sec./sec.
CUBIC CENTIMETERS	3.531×10^{-5}	Cubic feet
Cubic centimeters	6.102×10^{-2}	Cubic inches
Cubic centimeters	10^{-6}	Cubic meters
Cubic centimeters	1.308×10^{-6}	Cubic yards
Cubic centimeters	2.642×10^{-4}	Gallons
Cubic centimeters	10^{-3}	Liters
Cubic centimeters	2.113×10^{-3}	Pints (liq.)
Cubic centimeters	1.057×10^{-3}	Quarts. (liq.)

Multiply	By	To Obtain
CUBIC FEET	2.832×10^{4}	Cubic cms.
Cubic feet	1728	Cubic inches
Cubic feet	0.02832	Cubic meters
Cubic feet	0.03704	Cubic yards
Cubic feet	7.48052	Gallons U.S.
Cubic feet	6.23	Imper. Gallons
Cubic feet	28.32	Liters
Cubic feet	59.84	Pints (liq.)
Cubic feet	29.92	Quarts (liq.)
CUBIC FEET/MINUTE	472.0	Cubic cms./sec.
Cubic feet/minute	0.1247	Gallons/sec.
Cubic feet/minute	0.4720	Liters/sec.
Cubic feet/minute	62.43	Lbs. of water/min.
CUBIC FEET/SECOND	0.646317	Million gals./day
Cubic feet/second	448.831	Gallons/min.
CUBIC FOOT WATER	62.4	Pounds
Cubic foot water	998.8	Ounces
Cubic foot water	28.315	Kilograms
CUBIC INCHES	16.39	Cubic centimeters
Cubic inches	5.787×10^{-4}	Cubic feet
Cubic inches	1.639×10^{-5}	Cubic meters
Cubic inches	2.143×10^{-5}	Cubic yards
Cubic inches	4.329×10^{-3}	Gallons
Cubic inches	1.639×10^{-2}	Liters
Cubic inches	0.03463	Pints (liq.)
Cubic inches	0.01732	Quarts (liq.)
CUBIC METERS	10^{6}	Cubic centimeters
Cubic meters	35.31	Cubic feet
Cubic meters	61,023	Cubic inches
Cubic meters	1.308	Cubic yards
Cubic meters	264.2	Gallons U.S.
Cubic meters	220	Imperial Gallons
Cubic meters	10^{3}	Liters
Cubic meters	2113	Pints (liq.)
Cubic meters	1057	Quarts (liq.)
CUBIC YARDS	7.646×10^{5}	Cubic centimeters
Cubic yards	27	Cubic feet
Cubic yards	46,656	Cubic inches
Cubic yards	0.7646	Cubic meters
Cubic yards	202.0	Gallons
Cubic yards	764.6	Liters
Cubic yards	1616	Pints (liq.)
Cubic yards	807.9	Quarts (liq.)
CUBIC YARDS/MIN	0.45	Cubic feet/sec.
Cubic yards/min	3.367	Gallons/sec.
Cubic yards/min	12.74	Liters/sec.
DECIGRAMS	0.1	Grams
DECILITERS	0.1	Liters
DECIMETERS	0.1	Meters
DEGREES (ANGLE)	60	Minutes
Degrees (angle)	0.01745	Radians
Degrees (angle)	3600	Seconds
DEGREES/SEC	0.01745	Radians/sec.
Degrees/sec	0.1667	Revolutions/min.
Degrees/sec	0.002778	Revolutions/sec.
DEKAGRAMS	10	Grams

CONVERSION UNITS

Multiply	By	To Obtain
DEKALITERS	10	Liters
DEKAMETERS	10	Meters
DRAMS	27.34375	Grains
Drams	0.0625	Ounces
Drams	1.771845	Grams
FATHOMS	6	Feet
FEET	30.48	Centimeters
Feet	12	Inches
Feet	0.3048	Meters
Feet	1/3	Yards
FEET OF WATER	0.02950	Atmospheres
Feet of water	0.8826	Inches of mercury
Feet of water	0.03048	Kgs./sq. cm.
Feet of water	62.43	Lbs./sq. ft.
Feet of water	0.4335	Lbs./sq. inch
FEET/MIN.	0.5080	Centimeters/sec.
Feet/min.	0.01667	Feet/sec.
Feet/min.	0.01829	Kilometers/hr.
Feet/min.	0.3048	Meters/min.
Feet/min.	0.01136	Miles/hr.
FEET/SEC./SEC.	30.48	Cms./sec./sec.
Feet/sec./sec.	0.3048	Meters/sec./sec.
FOOT-POUNDS	1.286×10^{-3}	Br. Thermal Units
Foot-pounds	5.050×10^{-7}	Horse-power-hrs.
Foot-pounds	3.241×10^{-4}	Kilogram-calories
Foot-pounds	0.1383	Kilogram-meters
Foot-pounds	3.766×10^{-7}	Kilowatt-hrs.
FOOT-POUNDS/MIN.	1.286×10^{-3}	B. T. Units/min.
Foot-pounds/min.	0.01667	Foot-pounds/sec.
Foot-pounds/min.	3.030×10^{-5}	Horse-power
Foot-pounds/min.	3.241×10^{-4}	Kg.-calories/min.
Foot-pounds/min.	2.260×10^{-5}	Kilowatts
FOOT-POUNDS/SEC.	7.717×10^{-2}	B. T. Units/min.
Foot-pounds/sec.	1.818×10^{-3}	Horse-power
Foot-pounds/sec.	1.945×10^{-2}	Kg.-calories/min.
Foot-pounds/sec.	1.356×10^{-3}	Kilowatts
GALLONS	3785	Cubic centimeters
Gallons	0.1337	Cubic feet
Gallons	231	Cubic inches
Gallons	3.785×10^{-3}	Cubic meters
Gallons	4.951×10^{-3}	Cubic yards
Gallons	128	Fluid ounces
Gallons	3.785	Liters
Gallons	8	Pints (liq.)
Gallons	4	Quarts (liq.)
GALLONS, IMPERIAL	1.20095	U.S. Gallons
Gallons, U.S.	0.83267	Imperial gallons
Gallons Imperial	277.3	Cubic inches
Gallons Imperial	0.16	Cubic foot
Gallons Imperial	4.546	Liters
Gallons Imperial	0.00454	Cubic meter
GALLONS WATER	8.3453	Pounds of water
GALS. WATER (U.S.)	3.785	Kilograms

Multiply	By	To Obtain
GALS. WATER (IMP.)	10.02	Pounds
Gals. water (Imp.)	4.54	Kilograms
GALLONS/MIN.	2.228×10^{-3}	Cubic feet/sec.
Gallons/min.	0.06308	Liters/sec.
Gallons/min.	8.0208	Cu. ft./hr.
GALLONS WATER/MIN.	6.0086	Tons water/24 hrs.
GRAINS (TROY)	1	Grains (avoir.)
Grains (troy)	0.06480	Grams
Grains (troy)	0.04167	Pennyweights (troy)
Grains (troy)	2.0833×10^{-3}	Ounces (troy)
GRAINS/U.S. GAL.	17.118	Parts/million
Grains/U.S. gal.	142.86	Lbs./million gal.
GRAINS/IMP. GAL.	14.286	Parts/million
GRAMS	980.7	Dynes
Grams	15.43	Grains
Grams	10^{-3}	Kilograms
Grams	10^{3}	Milligrams
Grams	0.03527	Ounces
Grams	0.03215	Ounces (troy)
Grams	2.205×10^{-3}	Pounds
GRAMS/CM.	5.600×10^{-3}	Pounds/inch
GRAMS/CU. CM.	62.43	Pounds/cubic foot
Grams/cu. cm.	0.03613	Pounds/cubic inch
GRAMS/LITER	58.417	Grains/gal.
Grams/liter	8.345	Pounds/1000 gals.
Grams/liter	0.062427	Pounds/cubic foot
Grams/liter	1000	Parts/million
HECTOGRAMS	100	Grams
HECTOLITERS	100	Liters
HECTOMETERS	100	Meters
HECTOWATTS	100	Watts
HORSE-POWER	42.44	B. T. Units/min.
Horse-power	33,000	Foot-lbs./min.
Horse-power	550	Foot-lbs./sec.
Horse-power	1.014	H-power (Metric)
Horse-power	10.70	Kg.-calories/min.
Horse-power	0.7457	Kilowatts
Horse-power	745.7	Watts
HORSE-POWER (BOILER)	33,479	B. T. U./hr.
Horse-power (boiler)	9.803	Kilowatts
HORSE-POWER-HOURS	2547	Br. Thermal Units
Horse-power-hours	1.98×10^{6}	Foot-lbs.
Horse-power-hours	641.7	Kilogram-calories
Horse-power-hours	2.737×10^{5}	Kilogram-meters
Horse-power-hours	0.7457	Kilowatt-hours
INCHES	2.540	Centimeters
Inches	25.4	Millimeters
Inches	.0254	Meters
Inches	.0833	Foot
INCHES OF MERCURY	0.03342	Atmospheres
Inches of mercury	1.133	Feet of water

CONVERSION UNITS

Multiply	By	To Obtain
Inches of mercury	0.03453	Kgs./sq. cm.
Inches of mercury	70.73	Lbs./sq. ft.
Inches of mercury	0.4912	Lbs./sq. inch
INCHES OF WATER	0.002458	Atmospheres
Inches of water	0.07355	Inches of mercury
Inches of water	0.002540	Kgs./sq. cm.
Inches of water	0.5781	Ounces/sq. inch
Inches of water	5.202	Lbs./sq. foot
Inches of water	0.03613	Lbs./sq. inch
KILOGRAMS	980,665	Dynes
Kilograms	2.205	Lbs.
Kilograms	1.102×10^{-3}	Tons (short)
Kilograms	10^{3}	Grams
KGS./METER	0.6720	Lbs./foot
KGS./SQ. CM.	0.9678	Atmospheres
Kgs./sq. cm.	32.81	Feet of water
Kgs./sq. cm.	28.96	Inches of mercury
Kgs./sq. cm.	2048	Lbs./sq. foot
Kgs./sq. cm.	14.22	Lbs./sq. inch
KGS./SQ. MILLIMETER	10^{6}	Kgs./sq. meter
KILOLITERS	10^{3}	Liters
KILOMETERS	10^{5}	Centimeters
Kilometers	3281	Feet
Kilometers	10^{3}	Meters
Kilometers	0.6214	Miles
Kilometers	1094	Yards
KILOMETERS/HR	27.78	Centimeters/sec.
Kilometers/hr	54.68	Feet/min.
Kilometers/hr	0.9113	Feet/sec.
Kilometers/hr	0.5396	Knots
Kilometers/hr	16.67	Meters/min.
Kilometers/hr	0.6214	Miles/hr.
KMS./HR./SEC	27.78	Cms./sec./sec.
Kms./hr./sec	0.9113	Ft./sec./sec.
Kms./hr./sec	0.2778	Meters/sec./sec.
KILOWATTS	56.92	B. T. Units/min.
Kilowatts	4.425×10^{4}	Foot-lbs./min.
Kilowatts	737.6	Foot-lbs./sec.
Kilowatts	1.341	Horse-power
Kilowatts	14.34	Kg.-calories/min.
Kilowatts	10^{3}	Watts
KILOWATT-HOURS	3415	Br. Thermal Units
Kilowatt-hours	2.655×10^{6}	Foot-lbs.
Kilowatt-hours	1.341	Horse-power-hrs.
Kilowatt-hours	860.5	Kilogram-calories
Kilowatt-hours	3.671×10^{5}	Kilogram-meters
LITERS	10^{3}	Cubic centimeters
Liters	0.03531	Cubic feet
Liters	61.02	Cubic inches
Liters	10^{-3}	Cubic meters
Liters	1.308×10^{-3}	Cubic yards
Liters	0.2642	Gallons
Liters	2.113	Pints (liq.)
Liters	1.057	Quarts (liq.)
LITERS/MIN	5.886×10^{-4}	Cubic/ft./sec.
Liters/min.	4.403×10^{-3}	Gals./sec.

Multiply	By	To Obtain
$\frac{\text{LUMBER WIDTH (IN.) x THICKNESS (IN.)}}{12}$	Length (ft.)	Board Feet
METERS	100	Centimeters
Meters	3.281	Feet
Meters	39.37	Inches
Meters	10^{-3}	Kilometers
Meters	10^{3}	Millimeters
Meters	1.094	Yards
METERS/MIN	1.667	Centimeters/sec.
Meters/min.	3.281	Feet/min.
Meters/min.	0.05468	Feet/sec.
Meters/min.	0.06	Kilometers/hr.
Meters/min.	0.03728	Miles/hr.
METERS/SEC	196.8	Feet/min.
Meters/sec.	3.281	Feet/sec.
Meters/sec.	3.6	Kilometers/hr.
Meters/sec.	0.06	Kilometers/min.
Meters/sec.	2.237	Miles/hr.
Meters/sec.	0.03728	Miles/min.
METRIC TONS	2204.6	Pounds
Metric tons	1.1023	Short tons
MICRONS	10^{-6}	Meters
MILES	1.609×10^{5}	Centimeters
Miles	5280	Feet
Miles	1.609	Kilometers
Miles	1760	Yards
MILES/HR	44.70	Centimeters/sec.
Miles/hr.	88	Feet/min.
Miles/hr.	1.467	Feet/sec.
Miles/hr.	1.609	Kilometers/hr.
Miles/hr.	0.8684	Knots
Miles/hr.	26.82	Meters/min.
MILES/MIN	2682	Centimeters/sec.
Miles/min.	88	Feet/sec.
Miles/min.	1.609	Kilometers/min.
Miles/min.	60	Miles/hr.
MILLIERS	10^{3}	Kilograms
MILLIGRAMS	10^{-3}	Grams
MILLILITERS	10^{-3}	Liters
MILLIMETERS	0.1	Centimeters
Millimeters	0.03937	Inches
MILLIGRAMS/LITER	1	Parts/million
MILLION GALS./DAY	1.54723	Cubic ft./sec.
MINER'S INCHES	1.5	Cubic ft./min.
Miner's inches (Arizona, Cal., Mont., Nevada, Oregon)	11.25	G.P.M.

CONVERSION UNITS

Multiply	By	To Obtain
(Idaho, Kansas, Neb., N.M., N.D., S.D., Utah)	9	G.P.M.
MINUTES (ANGLE)	2.909×10^{-4}	Radians
OUNCES	16	Drams
Ounces	137.5	Grains
Ounces	0.0625	Pounds
Ounces	28.349527	Grams
Ounces	0.9115	Ounces (troy)
Ounces	2.790×10^{-5}	Tons (long)
Ounces	2.835×10^{-5}	Tons (metric)
OUNCES, TROY	480	Grains
Ounces, troy	20	Pennywghts. (troy)
Ounces, troy	0.08333	Pounds (troy)
Ounces, troy	31.103481	Grams
Ounces, troy	1.09714	Ounces, avoir.
OUNCES (FLUID)	1.805	Cubic inches
Ounces (fluid)	0.02957	Liters
OUNCES/SQ. INCH	0.0625	Lbs./sq. inch
PARTS/MILLION	0.0584	Grains/U.S. gal.
Parts/million	0.07016	Grains/Imp. gal.
Parts/million	8.345	Lbs./million gal.
PENNYWGHTS. (TROY)	24	Grains
Pennywghts. (troy)	1.55517	Grams
Pennywghts. (troy)	0.05	Ounces (troy)
Pennywghts. (troy)	4.1667×10^{-3}	Pounds (troy)
PINTS	0.4732	Liter
POUNDS (AVOIR.)	16	Ounces
Pounds (avoir.)	256	Drams
Pounds (avoir.)	7000	Grains
Pounds (avoir.)	0.0005	Tons (short)
Pounds (avoir.)	453.5924	Grams
Pounds (avoir.)	1.21528	Pounds (troy)
Pounds (avoir.)	14.5833	Ounces (troy)
Pounds (avoir.)	0.454	Kilograms
POUNDS (TROY)	5760	Grains
Pounds (troy)	240	Pennywghts. (troy)
Pounds (troy)	12	Ounces (troy)
Pounds (troy)	373.24177	Grams
Pounds (troy)	0.822857	Pounds (avoir.)
Pounds (troy)	13.1657	Ounces (avoir.)
Pounds (troy)	3.6735×10^{-4}	Tons (long)
Pounds (troy)	4.1143×10^{-4}	Tons (short)
Pounds (troy)	3.7324×10^{-4}	Tons (metric)
POUNDS OF WATER	0.01602	Cubic feet
Pounds of water	27.68	Cubic inches
Pounds of water	0.1198	Gallons
Pounds of water	0.10	Imp. gallon
LBS. OF WATER/MIN	2.670×10^{-4}	Cubic ft./sec.
POUNDS/CUBIC FOOT	0.01602	Grams/cubic cm.
Pounds/cubic foot	16.02	Kgs./cubic meter
Pounds/cubic foot	5.787×10^{-4}	Lbs./cubic inch
POUNDS/CUBIC INCH	27.68	Grams/cubic cm.
Pounds/cubic inch	2.768×10^{4}	Kgs./cubic meter
Pounds/cubic inch	1728	Lbs./cubic foot
POUNDS/FOOT	1.488	Kgs./meter
Pounds/inch	178.6	Grams/cm.
POUNDS/SQ. FOOT	0.01602	Feet of water
Pounds/sq. foot	4.883×10^{-4}	Kgs./sq. cm.
Pounds/sq. foot	6.945×10^{-3}	Pounds/sq. inch
POUNDS/SQ. INCH	0.06804	Atmospheres
Pounds/sq. inch	2.307	Feet of water
Pounds/sq. inch	2.036	Inches of mercury
Pounds/sq. inch	0.07031	Kgs./sq. cm.
QUARTS (DRY)	67.20	Cubic inches
QUARTS (LIQ.)	57.75	Cubic inches
QUINTAL, ARGENTINE	101.28	Pounds
Quintal, Brazil	129.54	Pounds
Quint., Castile, Peru	101.43	Pounds
Quintal, Chile	101.41	Pounds
Quintal, Mexico	101.47	Pounds
Quintal, Metric	220.46	Pounds
$\frac{1}{\text{SQ. FT./GAL./MIN.}}$	8.0208	Overflow rate. (ft./hr.)
TEMP. (°C.)+273	1	Abs. temp. (°C.)
Temp. (°C.)+17.78	1.8	Temp. (°F.)
Temp. (°F.)+460	1	Abs. temp. (°F.)
Temp. (°F.)−32	5/9	Temp. (°C.)
TONS (LONG)	1016	Kilograms
Tons (long)	2240	Pounds
Tons (long)	1.12000	Tons (short)
TONS (METRIC)	10^{3}	Kilograms
Tons (metric)	2205	Pounds
TONS (SHORT)	2000	Pounds
Tons (short)	32000	Ounces
Tons (short)	907.18486	Kilograms
Tons (short)	2430.56	Pounds (troy)
Tons (short)	0.89287	Tons (long)
Tons (short)	29166.66	Ounces (troy)
Tons (short)	0.90718	Tons (metric)
TONS OF WATER/24 HRS.	83.333	Pounds water/hr.
Tons of water/24 hrs.	0.16643	Gallons/min.
Tons of water/24 hrs.	1.3349	Cu. ft./hr.
WATTS	0.05692	B. T. Units/min.
Watts	44.26	Foot-pounds/min.
Watts	0.7376	Foot-pounds/sec.
Watts	1.341×10^{-3}	Horse-power
Watts	0.01434	Kg.-calories/min.
Watts	10^{-3}	Kilowatts
WATT-HOURS	3.415	Br. Thermal Units
Watt-hours	2655	Foot-pounds
Watt-hours	1.341×10^{-3}	Horse-power hrs.
Watt-hours	0.8605	Kilogram-calories
Watt-hours	367.1	Kilogram-meters
Watt-hours	10^{-3}	Kilowatt-hours

SEWAGE CHARACTERISTICS

Gordon L. Van Fleet

Engineer
Division of Sanitary Engineering

INTRODUCTION

The development of communities as centers of concentration of population has created numerous social problems not the least of which are the provision of a safe water and the adequate disposal of wastes. In the 19th Century several large European cities initiated the use of closed conduits or pipes for the collection of human wastes when it became apparent that the use of the streets as open sewers was creating increasingly intolerable living conditions. Although the sewage was removed from the doorstep, its discharge to nearby rivers and streams produced obnoxious odours and unsightly conditions in highly desirable recreational areas.

At the same time diseases of epidemic proportion were traced to water supplies originating from these same rivers and streams. Tiny organisms called bacteria were discovered in sewage, some of which were found to be responsible for such diseases as typhoid fever, paratyphoid fever, dysentery and cholera. A two-fold solution to the problem thus became apparent, involving both sewage and water treatment.

A more intensive study of bacterial types has disclosed that only a small number of them are responsible for disease. These and other bacteria are destroyed in nature through the activities of higher forms of microbial life. Together the organisms play a major role in degrading or breaking down organic matter (dead plants and animals and their wastes). Through the harnessing of these organisms, under optimum conditions such as are provided in a sewage treatment plant, the degradation of organic wastes can be speeded up and controlled.

SOURCES OF SEWAGE

In nature sewage is present as the waste product of human and animal life. Man, through his resourcefulness, has added to this the waste products of industrial and commercial activity. Thus sewage has become complex in its composition varying widely in both volume and concentration.

Domestic wastes are those that originate in the household from the bathroom, the kitchen and the laundry-room. These can be readily treated in a properly designed sewage treatment plant. Industrial and commercial waste products may also be acceptable for treatment in a municipal sewage plant. However, in some instances, it may be necessary to treat them separately due to their complex nature.

QUANTITY OF SEWAGE

In addition to carrying domestic and industrial wastes the sanitary sewers may receive large quantities of water from rain and street washings. Water in the ground may also enter sewers through broken pipes, poorly constructed sewer lines and illegal storm sewer connections. Older sewer systems may combine the collection of sanitary sewage and storm water in a single sewer, however, present practice requires the separate collection of each. This is understandable when it is realized and a treatment plant must be designed on the basis of the total flows reaching it. Thus it becomes very uneconomical to construct a large plant for the prupose of treating immense quantities of very dilute sewage.

The total quantity of sewage reaching the plant is called the hydraulic load and this will vary from hour to hour and differ from day to day. Normally flows will range between 70 and 130 per cent of the water consumption. The percentage will be increased if infiltration is a factor while it will be lowered due to lawn watering, car washing, hydrant flushing and many other domestic and industrial uses for which the water is not directed to the sanitary sewer system. An average municipality without large industrial sewage contributors may generate approximately 100 gallons of sewage

per person per day. It is interesting to note that solids account for less than 0.1 of 1 per cent by weight of the total sewage flow. The remaining 99.9 per cent is water which provides a means of carrying the solids through the sewer pipes.

SEWAGE CHARACTERISTICS

A treatment plant removes contaminants from sewage making it acceptable for discharge to lakes or streams. In so doing, the physical, chemical and bacteriological characteristics of the sewage are changed. These changes can best be seen by comparing the characteristics of the raw sewage, primary effluent and final effluent of a treatment plant. Sketch No. 1 shows the raw sewage entering the plant with the primary effluent comprised of the liquid leaving the primary settling tank (clarifier). When the sewage undergoes biological treatment, or secondary treatment, the liquid discharge is called the plant or final effluent.

A. Physical Characteristics

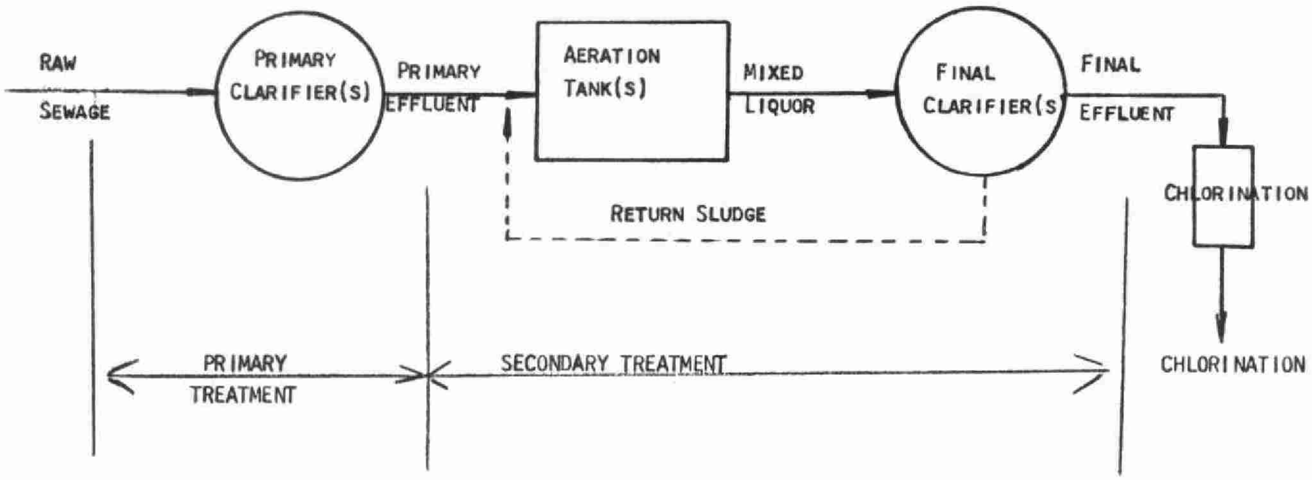
The physical characteristics of sewage are those which affect our senses and would include temperature, turbidity, colour and odour. Table No. 1 compares the physical changes which take place through a typical treatment plant.

TABLE NO. I

	Temperature	Turbidity	Colour	Odour
Raw Sewage	varies	high in solids	milky-grey to black	musty to sulphurous
Primary Effluent	lower temperature	fine non-settleable solids	greyish to colourless	musty to sulphurous
Final Effluent	lower temperature	no visible solids	clear colourless	fresh chlorinated

SKETCH NO. 1

TYPICAL SEWAGE TREATMENT PLANT



The temperature of raw sewage will vary depending upon the source of water supply for the municipality. However, the resultant raw sewage is always somewhat warmer. As the sewage passes through the treatment plant the temperature decreases. The higher the sewage temperature the more rapid the decomposition and the better the settleability.

Raw sewage is highly turbid, containing many different types of solids such as paper, rags, garbage, feces, sand and silt. Primary effluent will contain finely suspended and floating matter which can be removed through biological treatment, producing a clear, colourless final effluent.

The normal milky-grey colour of raw sewage will not be evident if coloured industrial wastes or partially decomposed sewage are involved. Septic or partially decomposed sewage is dark, sometimes black in colour with a sulphurous odour. Normal sewage smells musty but not unpleasant. Primary effluent will be similar to raw sewage except that a large portion of the solids have been removed. The final effluent of a properly operated secondary treatment plant will be clear and colourless with a fresh, often chlorinated odour.

B. Chemical Characteristics

Chemically, sewage is composed of a great many inorganic and organic solids which are carried in water. In addition the sewage may contain dissolved gases and living organisms. Inorganic or fixed substances are recognized by the fact that they are inert and generally not subject to decay or combustion. On the other hand, organic materials will decompose and are sometimes called volatile matter since they will burn when heated to high temperatures.

Inorganic and organic substances which can be seen in the sewage are known as suspended solids. These are the solids which can be removed from the sewage by physical or mechanical means, such as sedimentation or filtration. Those that cannot be readily seen are classified as dissolved

solids. A third group called colloidal solids can be loosely described as very fine particles which are non-settleable. These may or may not be visible to the naked eye. For simplification the colloidal solids classification will be grouped partially as suspended solids and partially as dissolved solids. Total solids, as the name implies, includes all of the solids constituents of sewage.

Quantities or concentrations of solids, whether inorganic or organic will differ from hour to hour and from sewage plant to sewage plant. Average concentrations of solids in a medium strength sewage are shown graphically in Sketch No. 2. The amounts of suspended solids and organic material present in the sewage indicate the stength of the sewage. The successful operation of a treatment plant depends, to a great extent, upon this sewage strength.

Inorganic Solids

This material consists of sand, silt, clay, the dissolved minerals and salts in community water supplies and any other inert matter contained in wastes discharged to the sewers. Thus a hard water will produce a high mineral content in the sewage. Some of the more common minerals and salts found in sewage are sulphates, carbonates, bicarbonates and chlorides of calcium, magnesium, sodium, potassium and iron. In an average domestic sewage these are not normally troublesome to a sewage treatment process.

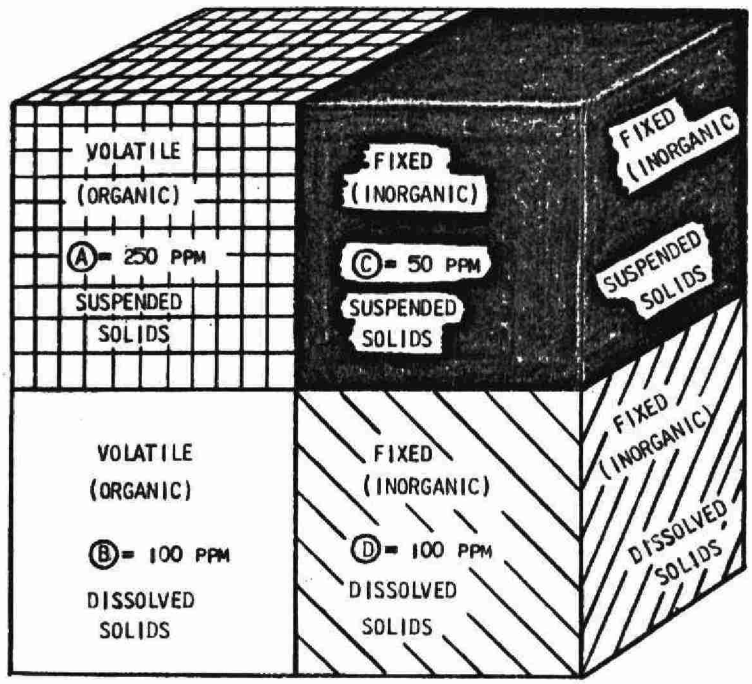
Organic Solids

Organic solids are generally of animal or vegetable origin including the waste products of animal and vegetable life. Some synthetic compounds, however, are also organic in nature. All organic matter consists of hydrogen, oxygen and carbon. These substances may be combined with inorganic nitrogen, sulphur or phosphorus. The principal groups formed are called proteins, carbohydrates and fats. These serve as food for bacteria and higher forms of organisms resulting in decomposition or decay of the organic matter. Decomposition leads to the formation of carbon dioxide, nitrogenous compounds consisting of ammonia, nitrites and nitrates, and sulphurous

SKETCH NO. 2

COMPOSITION OF SOLIDS IN A MEDIUM

STRENGTH RAW SEWAGE



TOTAL SOLIDS = A + B + C + D = 250 + 100 + 50 + 100 = 500 PPM

TOTAL VOLATILE SOLIDS = A + B = 250 + 100 = 350 PPM

TOTAL FIXED SOLIDS = C + D = 50 + 100 = 150 PPM

TOTAL SUSPENDED SOLIDS = A + C = 250 + 50 = 300 PPM

TOTAL DISSOLVED SOLIDS = B + D = 100 + 100 = 200 PPM

substances comprised of sulphates as well as hydrogen sulphide gas. These waste products are in turn utilized by plant and animal life in their growth processes. The cycles of life, death and decay involving carbon, nitrogen and sulphur are shown in Sketches No. 3, 4 and 5 respectively.

The organic strength of sewage is principally a measure of its capacity to undergo decomposition. The standard criteria for determining the organic strength of sewage is called the Biochemical Oxygen Demand or BOD. The BOD is simply a measure of the oxygen utilized in decomposing organic matter to a stable condition. Normally the test is carried out at a temperature of 20°C over a period of five days with the result being reported in ppm. 5-day BOD (BOD_5).

Domestic raw sewage will normally have a BOD_5 ranging between 100 ppm and 300 ppm. Industrial wastes could significantly change this however. During primary treatment the BOD_5 generally drops by 30 to 40 per cent, with full secondary treatment reducing the BOD_5 by approximately 95 per cent. The final effluent in a well operated plant should not contain more than 15 ppm BOD_5.

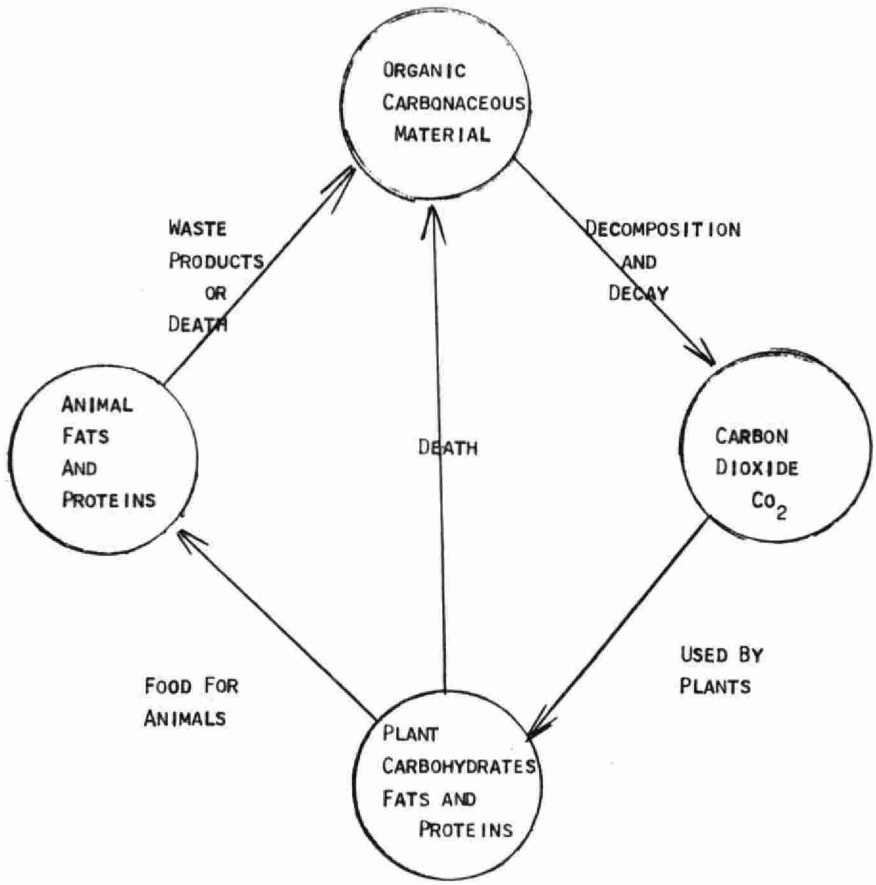
Dissolved Gases

Sewage contains small and varying concentrations of dissolved gases. Among the most important of these is oxygen, present in the original water supply and also dissolved from air in contact with the surface of flowing sewage. In addition to dissolved oxygen, sewage may contain other gases such as carbon dioxide, ammonia and hydrogen sulphide, the products of decomposition, as well as nitrogen dissolved from the atmosphere. These gases, although small in amount, may serve as indicators of the degree of decomposition of sewage.

Solids

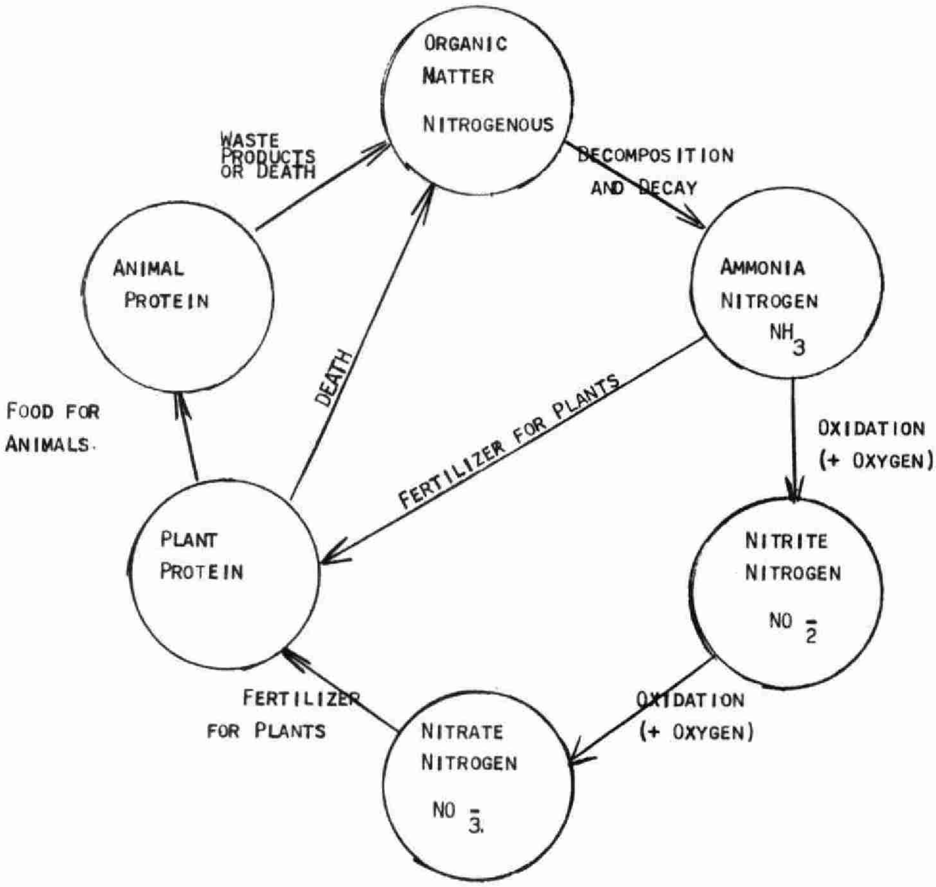
The total solids in a sewage are the combination of all inorganic and organic solids or the total of the suspended and dissolved solids. From Sketch No. 2 it can be seen that the concentration of total solids in an average medium strength sewage is given as 500 ppm. This consists

SKETCH NO. 3



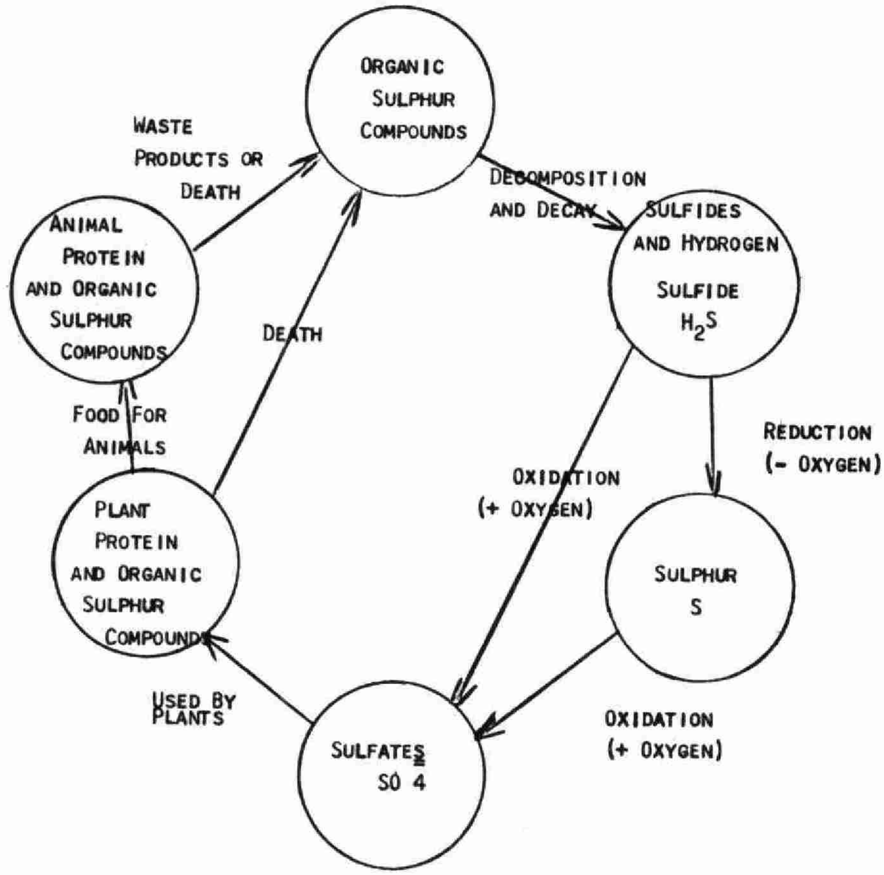
CARBON CYCLE

SKETCH NO. 4



NITROGEN CYCLE

SKETCH NO. 5



SULPHUR CYCLE

of 350 ppm organic matter in addition to 150 ppm inorganic matter. The same total solids figure is arrived at by adding the suspended and dissolved solids which are shown as 300 ppm and 200 ppm respectively. The figures presented are only for purposes of example and should not be considered optimum or necessary in any particular municipality.

The addition of storm or ground water into the sewage may change these solids relationships significantly. Similarly the introduction of industrial wastes may increase the solids content, particularly the organic solids, with very definite variations in the strength of the sewage. Also, sewage varies widely in both composition and volume from hour to hour depending upon changes in community activities. Sewage is likely to be at its maximum strength and flow during the day-time and at a minimum during the night hours. On weekends and holidays flows and strength are frequently reduced due to the lowered rate of communal activity. Therefore no data on sewage can be applied equally to all sewages at all times.

A primary treatment plant will normally reduce suspended solids by 40 to 60 per cent. Complete secondary treatment generally will remove 90 to 95 per cent of the suspended solids producing a final effluent with suspended solids less than 15 ppm.

Nutrients

Nitrogen and phosphorus are the two nutrients which are of greatest concern in the operation of a sewage treatment plant. It has been generally concluded that a nitrogen-to-BOD ratio of 1-to-20 and a phosphorus-to-BOD ratio of 1-to-100 by weight is essential for optimum growth of organisms involved in the decomposition of organic matter. Domestic sewage normally contains an excess of both nitrogen and phosphorus. This excess, when discharged in the plant effluent acts as a fertilizer in promoting the growth of algae in receiving waters.

Total nitrogen is present in organic wastes in the form of ammonia nitrogen, organic nitrogen, nitrite nitrogen and nitrate nitrogen each representing a different stage of waste stabilization. Table No. 2 summarizes the ranges of

typical nitrogen analyses for a conventional sewage treatment plant.

TABLE 2

Nitrogen Concentrations

	Ammonia Nitrogen (ppm)	Organic Nitrogen (ppm)	Nitrite Nitrogen (ppm)	Nitrate Nitrogen (ppm)
Raw Sewage	15-50	25-85	less than 0.1	less than 0.5
Primary Effluent	15-50	25-85	less than 0.1	less than 0.5
Final Effluent	0-1	5-20	less than 5.0	greater than 10

While nitrogen may change form during decomposition, the total nitrogen loss through a conventional secondary treatment plant is generally very low. Sewage oxidation ponds or lagoons have, however, been found to be successful in the removal of nutrients. Ammonia nitrogen was reportedly reduced from 75 to 90 per cent with organic nitrogen reduced by 60 per cent and phosphorus reduced by 96 per cent.

C. Bacteriological Characteristics

Sewage contains countless numbers of living organisms, most of them too small in size to be visible except with the use of a microscope. They are a natural living part of the organic matter found in sewage and they are important because they are one of the reasons for the success of our present treatment processes. The microscopic living organisms in sewage may generally be considered to consist of bacteria and other more complex higher forms of organisms.

Fresh raw sewage may normally contain from 10 to 200 million bacteria per 100 millilitres. These bacteria may either be harmful or non-harmful to humans. Complete secondary treatment may be expected to reduce these numbers by from 80 to 95 per cent with effluent chlorination increasing the per cent "kill" to 99.9 per cent or better. The highest

reductions are generally only attained when the treatment plant is operating efficiently.

SEWAGE PLANT PROCESSES

K. A. Reichert
Engineer
Division of Sanitary Engineering

INTRODUCTION

This introductory lecture is intended to provide a basic outline of the sewage treatment processes presently available. Although reference is made to the purposes and applications of the various processes, design details are not dealt with since these will be reviewed in greater detail during the remainder of this course and the two courses which will follow in the future. No attempt is made to cover the treatment of chemical industrial wastes but the processes that are described are applicable to organic industrial wastes.

NATURE OF SEWAGE

Municipal sanitary sewage normally contains 99.5% water with the remaining 0.5% consisting of solids suspended or dissolved in the water. These solids may be described as follows:

1. Grit - heavy material such as sand or gravel, inorganic.

2. Settleable solids - solid material, organic or inorganic, which will settle out when low flow conditions are present.

3. Floating solids - solid material which will float when subjected to low flow conditions such as grease and scum.

4. Fine colloidal material - very small particles of solid material which is not readily removed by adjustment in the rate of flow.

5. Dissolved substances - solids in solution, i.e., sugar in water.

The processes which will be described provide for the removal of the above material at varying rates of efficiency together with an associated removal of biochemical oxygen demand.

Since sewage from different municipalities will differ in the chemical characteristics, the actual type of sewage treatment adopted will depend on the characteristics of the sewage and the size of the municipality.

OBJECTIVES OF SEWAGE TREATMENT

The objectives of sewage treatment will vary according to the location of the treatment facility and the method of disposal.

There are three different methods of sewage disposal which may be utilized as follows:

1. On the surface of the land. The sewage raw or partially treated can be sprayed onto land for final disposal. Also broad irrigation using the ridge and furrow method may sometimes be utilized.

2. Sub-surface disposal areas employ weeping tiles or seepage pits for final disposal of the sewage. Here again the sewage requires generally only partial treatment, i.e., coarse solids removal, dependent of course upon the soil characteristics of the tile bed area.

3. Discharge to surface waters where generally a very high degree of treatment is required since this method relies on the dilution provided by the receiving water.

This latter procedure is the most common used for final disposal of the treated sewage at municipal sewage treatment plants.

Therefore, sewage treatment plants employ processes for the removal of coarse material, separation of the fine particles of solids from the water (clarification), stabilization of sewage for the removal of the organics which create

a biochemical oxygen demand and the destruction of harmful bacteria or other organisms.

SEWAGE TREATMENT PROCESSES

General

As noted previously, the processes to be described will be the types which are commonly used for municipal sewage treatment. Also since the common practice is to discharge the final effluent into a water way, the processes which do not have the discharges to the watercourse are not discussed in this paper. The number of this latter type of plants in the province is very limited and generally all have been provided with percolation ponds to which the treated sewage is discharged for final seepage into the ground. It should be noted that in instances where higher degrees of treatment are required for the protection of the receiving water, the capital, operational and maintenance costs of the treatment plant increase accordingly.

Primary Treatment

Primary treatment is a term applied to processes where grit, screenings, and settleable material are removed by physical methods. The processes involved are:

1. Grit removal - tanks are provided where the raw sewage is passed through the tank at a design velocity of approximately one foot per second for the removal of the grit. The grit is then disposed of on land or in sanitary land fill.

2. Screening - coarse or fine screens are provided which can be manually or mechanically cleaned for the removal of large floating objects in the sewage. These objects will include pieces of wood, paper, etc. Here the material is removed from the raw sewage for disposal generally in a sanitary land fill.

3. Comminution - grinders, cutters, or shredders where the large particles are ground up so that the size is reduced and the particles are then returned to the raw sewage.

Normally a treatment plant is provided with screening or comminution equipment to handle the large solids. In instances where both pieces of equipment are provided, the screening is normally used as a "back-up" for the comminution equipment.

4. Primary sedimentation - includes septic tanks, two storey tanks with separate sludge compartments, plain sedimentation with mechanical sludge removal, primary clarifiers with mechanical sludge removal. The latter two types of tanks with the mechanical sludge removal equipment are normally used in municipal sewage treatment plants with the former two being considered as relics of the past.

Generally primary sewage treatment units are designed for the removal of up to 60 per cent of the suspended solids with an associated reduction in the biochemical oxygen demand of between 30 and 35 per cent. The primary sewage treatment process is normally used to provide an initial degree of treatment prior to discharging the sewage to a secondary treatment plant or is in some cases all the treatment that is provided where the effluent is discharged to a large waterway with a very high dilution factor. The sewage is normally disinfected prior to discharge to a watercourse.

Secondary Treatment

Secondary treatment is the term applied to biological processes providing a higher degree of efficiency than primary treatment. Organisms essential to the process require oxygen and there are no odours, providing aerobic conditions are maintained. The following types of processes are considered as secondary treatment:

1. Activated sludge - the conventional activated sludge plant consists of aeration tanks sized to provide approximately six hours retention based on the average raw sewage flow to the plant with final settling tanks provided for the separation of the biological floc which is grown in the aeration tank from the water. The final effluent is discharged from the top of the tank as the clear liquid with the biological floc is pumped from the bottom of the tank to the inlet of the aeration tanks. A portion of this biological floc, or activated sludge,

is wasted to the primary settling tank. The primary settling tank performs a similar function from which the sludge is pumped off the bottom for further treatment and disposal. Numerous variations of the conventional activated sludge process have been developed and are briefly outlined as follows:

(a) Extended aeration activated sludge - the plant is preceded by only grit and screening removal facilities. The raw sewage is discharged without primary treatment to the aeration tanks which in turn provide a retention time of approximately 24 hours. The effluent from the aeration tanks is discharged to the final settling tanks for separation of the activated sludge and the water. The activated sludge is returned to the inlet of the aeration tanks. Normally sludge holding tanks are provided to receive waste activated sludge which is not returned to the aeration tanks. The sludge holding tanks are periodically pumped into trucks for final disposal.

(b) Step aeration - this plant is very similar to the conventional activated sludge plant with the exception that the sewage from the primary settling tank is discharged to the aeration tanks not only at the inlet end but periodically along the length of the tank. The attempt here is to reduce the effect of shock loading on the aeration section.

(c) Contact stabilization - grit and screening facilities are provided only for primary treatment with the raw sewage being discharged to a very small aeration tank normally with a retention time of approximately 60 to 90 minutes from which the sewage is directed to final settling tanks. The recirculated activated sludge from the final settling tank is discharged to a re-aeration tank which has a relatively long retention time. The effluent from the re-aeration tank is returned to the contact tank to complete the process. Waste activated sludge is normally discharged from the re-aeration tank to an aerobic digestion tank or some other form of sludge treatment.

(d) High rate - this is a relatively new development in the sewage treatment plant process where extremely high rates of primary effluent are applied to the aeration tanks which are

of course, followed by the final settling tanks with recirculated activated sludge rates in excess of 100 per cent. The attempt with this type of treatment is to provide the same degree of treatment using less tankage.

Plants of this type with primary settling tanks normally utilize heated, anaerobic sludge digestion as the method of sludge treatment. Plants not equipped with primary settling facilities are usually provided with aerobic digesters for sludge treatment.

In all of the above processes a very high degree of treatment is achieved with final effluent biochemical oxygen demands between 15 parts per million and 25 parts per million. The larger plants in the Province are generally of the conventional activated sludge type with the modifications being utilized normally in the small communities.

2. Oxidation ditch - this method of treatment involves the construction of a ditch in the shape of a race track to which the sewage is discharged for aeration followed by final settling facilities. The design criteria of this type of plant is similar to that of an extended aeration tank. The main feature is the method of aeration. The plants referred to in item number 1 above normally all use diffused aeration or mechanical aeration of the type where a vertical shafted propeller is suspended in the liquid to provide the aeration. With the oxidation ditch a "brush" rotor is utilized which is essentially the same as a paddle wheel to propel the sewage around the ditch and provide the necessary aeration.

3. Waste stabilization ponds - waste stabilization ponds or lagoons have been utilized for the treatment of sewage where land is available. The conventional pond is designed with a maximum water depth of five feet and a retention time of approximately 120 days. Aerated ponds have been constructed with aeration times of one day to five days. As yet the efficiency from these lagoons is not comparable to the types of processes outlined in items number 1 and 2. However, the conventional lagoon can be constructed for discharge to a waterway which does not have a sufficient flow in the summer to receive the effluent from a mechanical sewage treatment

plant. The lagoon can be used to store the sewage during the critical summer months for discharge during the fall. A lagoon of the conventional type is normally designed on the basis of a requirement of 100 persons per acre or 20 pounds of biochemical oxygen demand per acre per day. On occasion, the lagoons have been designed to provide six months storage where the characteristics of the receiving stream or its use for recreational purposes is critical.

A conventional lagoon, due to its size, utilizes the processes of nature for the reduction of the organic content in raw sewage. There is no sludge build-up in the bottom of a conventional lagoon and consequently the operation and maintenance of the lagoon is restricted to careful control of the liquid level structures and cutting of grass.

4. Trickling filters - trickling filter plants have been used in the past to provide secondary treatment. However, these plants are adversely affected by the climatic conditions in Ontario and, therefore, have not provided generally the treatment efficiency required of secondary treatment plants. As a result, a number of plants in the Province have been converted to activated sludge plants.

The manufacturers have produced "package" plants particularly of the modified activated sludge process which can be purchased as opposed to a custom built plant. Normally these package plants are smaller in size ranging upwards to one million gallons per day.

Sludge Treatment

The sewage solids removed by the processes described are generally treated to reduce the volume and to stabilize the sludge. The term stabilization is used to mean the changing of the state of the sludge so that it is in a form which can be readily handled and dried without creating odour problems or other nuisances. A large variety of processes are available for the treatment of sludge and the basic types are outlined as follows:

1. Anaerobic heated sludge digestion in which the sludge is

discharged to closed tanks which are heated to approximately 95 degrees F. A biological process reduces the water content of the sludge and provides a product which can be filtered to further reduce the volume of sludge to be handled by trucking.

2. Vacuum filtration - this method may be followed for the treatment of raw sludge from a primary settling tank or for further concentration of the digested sludge from heated digesters.

3. Sand beds - the sludge from the heated digester can be discharged to sand beds to drain the water out of the sludge for return to the plant.

4. Incineration or drying - the digested or filtered sludge can be placed into an incinerator for burning or drying, depending on the ultimate method of disposal. Generally, with incineration plants both heated digesters and vacuum filtration are provided.

5. Aerobic digestion - it is noted that some of the processes for secondary treatment utilize aerobic digestion as a method of handling the waste sludge. Normally the concentrated sludge is trucked for land disposal.

6. Centrifuging - some work has been carried out on the use of large centrifuges for the separation of the sludge solids from the water. To date mechanical difficulties have generally restricted the use of this method of sludge treatment.

It must be recognized that the raw sludge collected from a primary settling tank normally has a moisture content of approximately 98 per cent, i.e., 100 gallons of sludge contains two gallons of solid material mixed in 98 gallons of water.

Final disposal is generally on the land and in some cases, sludge lagoons have been used. Difficulties with odours depend on the degree of stabilization provided by the treatment prior to final disposal.

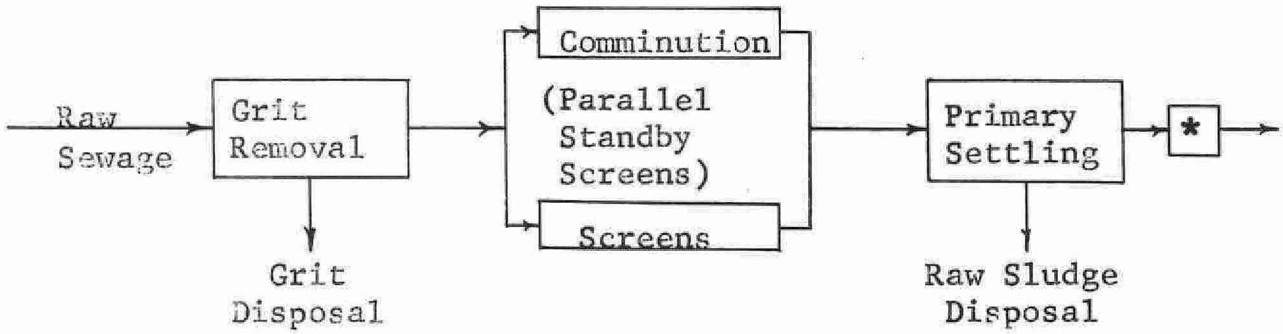
Effluent Polishing and Tertiary Treatment

Effluent polishing and tertiary treatment are provided in cases where the degree of treatment provided at a secondary sewage treatment plant is not adequate for discharge of the effluent to the receiving water. Effluent polishing is defined as the removal of suspended matter and biochemical oxygen demand. Tertiary treatment is defined as the removal of nutrients such as nitrogen and phosphorus. Numerous effluent polishing systems have been constructed including the use of waste stabilization ponds after a secondary treatment plant, sand filters and high rate mechanical filters. Tertiary treatment can sometimes be effected by the use of lime injected into the supernatant return from the digester to the plant. This will remove a percentage of phosphorus which would ultimately be discharged in the sewage treatment plant effluent. Some research work has been undertaken for the removal of nitrogen through the use of controlled aeration in the plant itself and aeration towers for the final effluent. However, to date both forms of tertiary treatment are still in the development stage and have not been widely accepted primarily due to cost.

Disinfection

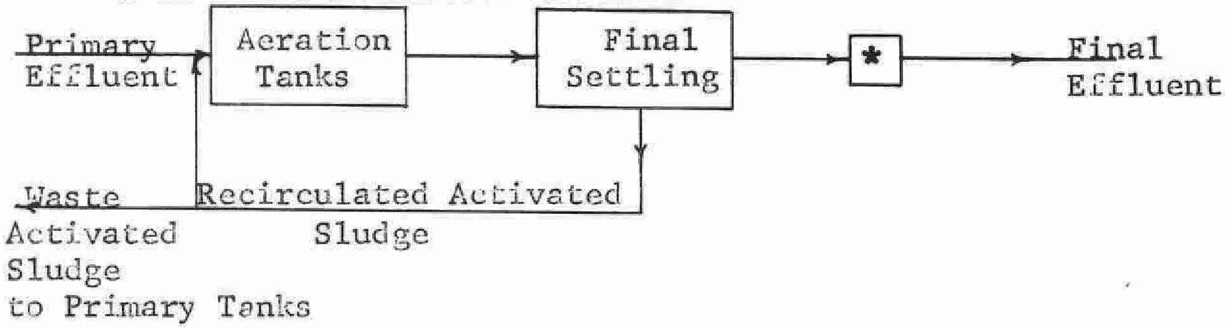
Disinfection is commonly accomplished by effluent chlorination. Where chlorination facilities are installed in a treatment plant, provision is generally made for chlorine application at other points to assist in odour control and treatment adjustments. The prime purpose of disinfection however is to kill the bacteria and other small organisms which are harmful to human beings.

PRIMARY TREATMENT

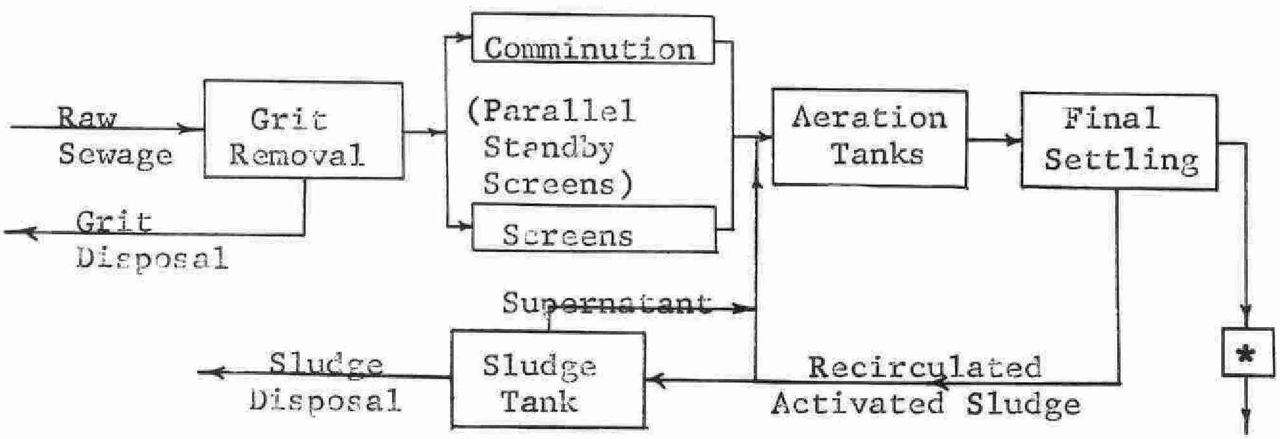


SECONDARY TREATMENT

Conventional Activated Sludge

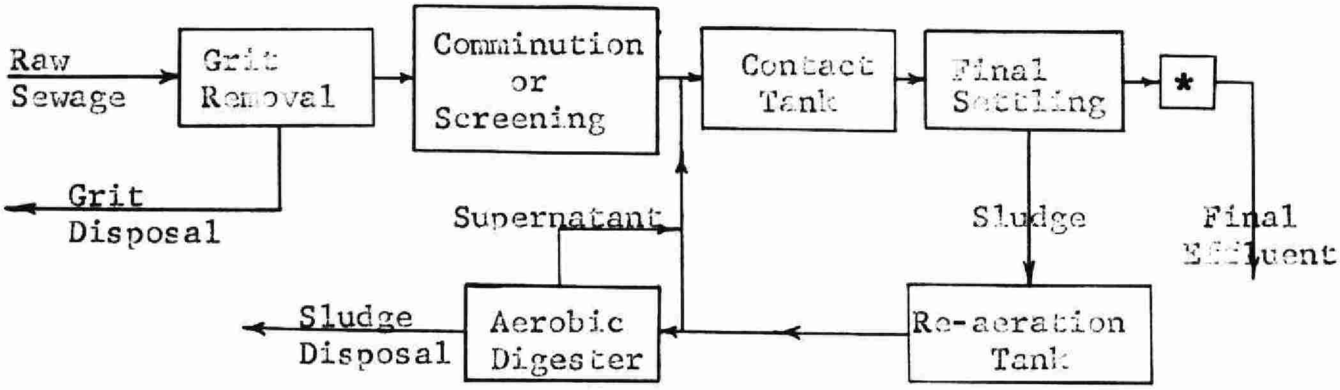


Extended Aeration

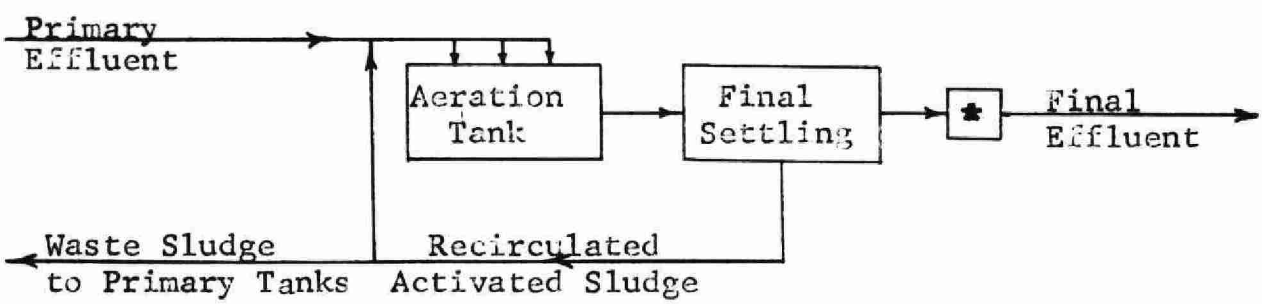


* Chlorination if Effluent Discharged to Receiving Water.

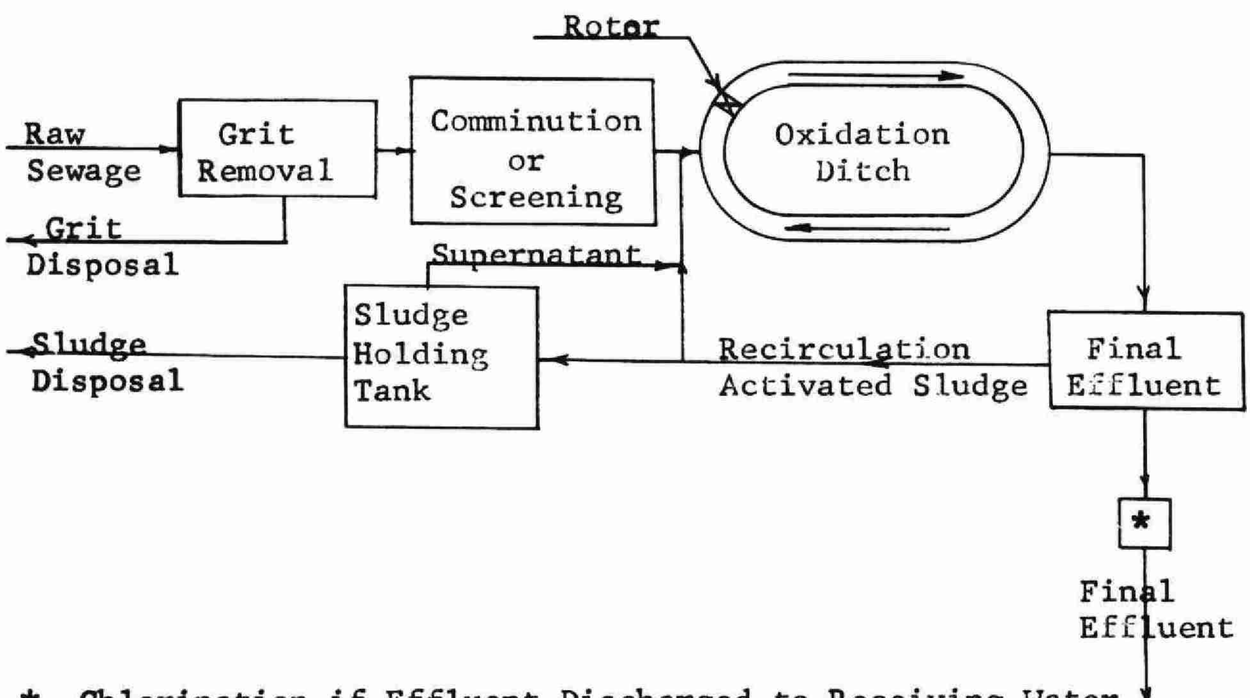
Contact Stabilization



Step Aeration



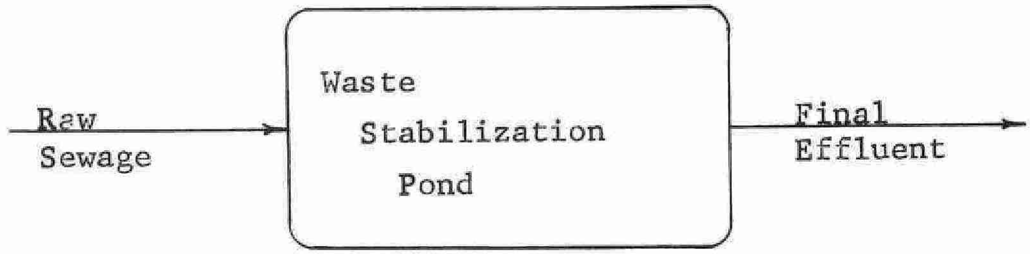
Oxidation Ditch



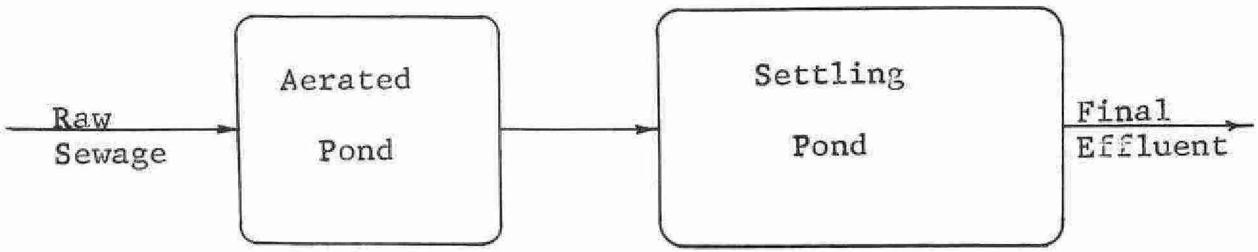
* Chlorination if Effluent Discharged to Receiving Water.

WASTE STABILIZATION PONDS

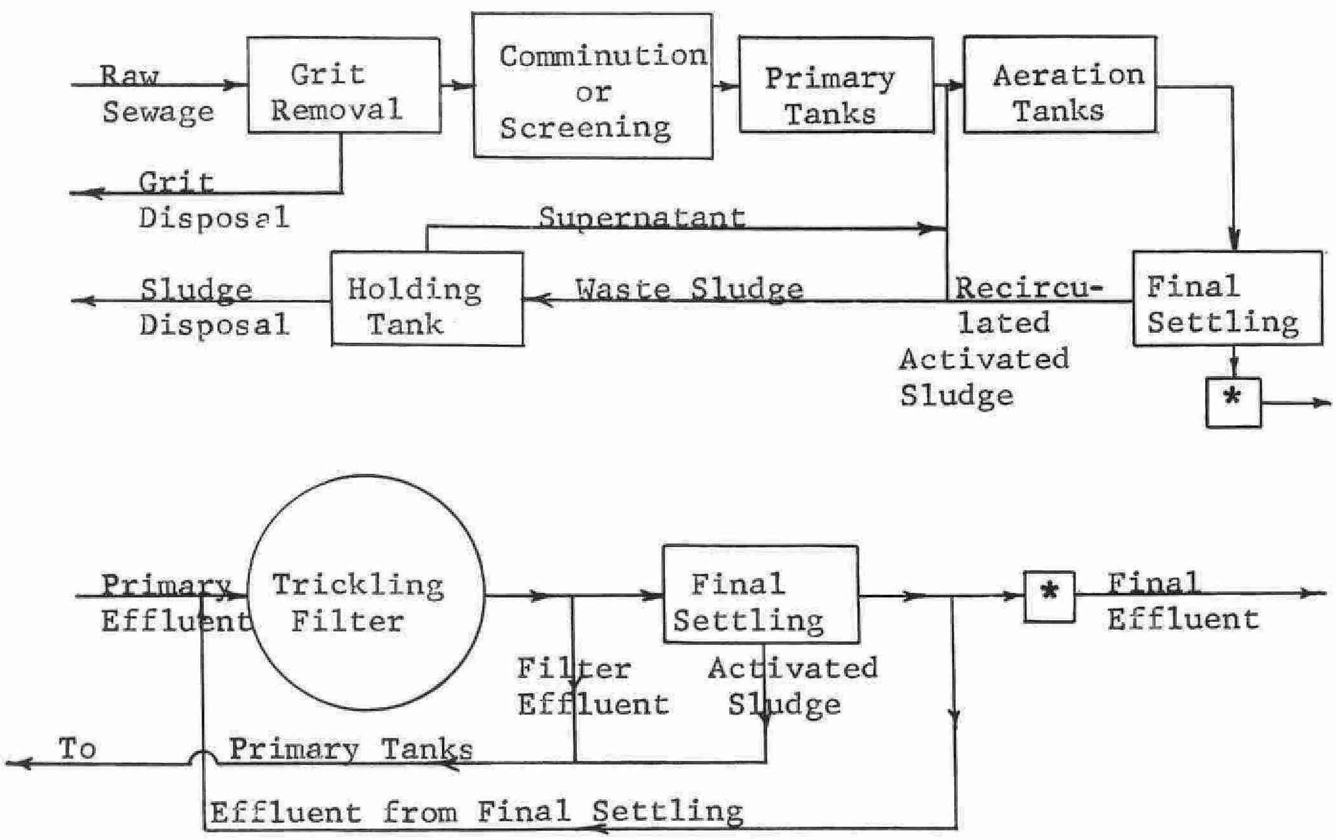
Conventional Ponds



Aerated Ponds



High Rate



* Chlorination if Effluent Discharged to Receiving Water.

THE EFFECTS OF SANITARY WASTES ON LIFE IN RECEIVING WATERS

G. Owen
Biology Branch
Division of Laboratories

INTRODUCTION

The purpose of this talk is threefold; to illustrate briefly what life is like in natural waters, to describe what changes to the animals and plants occur where sanitary wastes are discharged, and to indicate how sewage plant operators can reduce the harmful effects of sanitary wastes to aquatic life.

BIOLOGY OF LAKES AND STREAMS

Let us begin by noting three generalizations about life in unpolluted water.

Firstly, all the living organisms in a stream or lake form a balanced system which is often referred to as a network of food chains. Each link in each chain depends on the previous link for its food. The big animals eat little animals which eat plants which make their own food from sunlight and nutrients dissolved in the water.

One simple food chain starts with the tiny one-celled plant Chlorella, which is eaten by the water flea, Daphnia. Daphnia may be eaten by minnows, which may be eaten by trout, which may be eaten by Man (if he is lucky enough to catch the trout). In this particular case, Man stands at the head of a food chain containing five members (Figure 1).

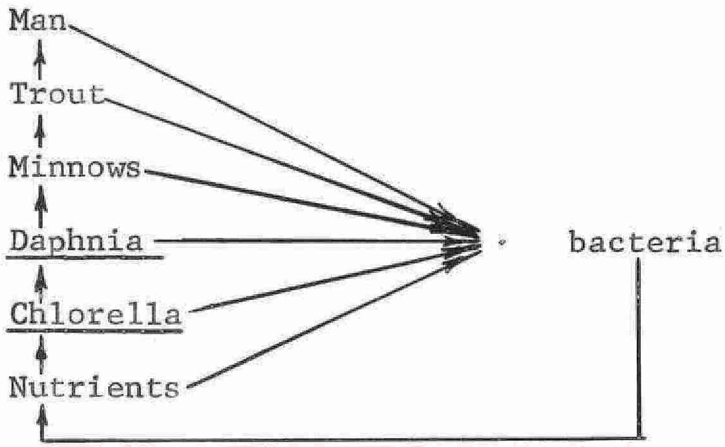


Figure 1. A simple food chain

The matter of course does not end here. All the dead plants and animals, and all their waste products, are broken down by bacteria to form nutrients again, and so the cycle is repeated.

The second generalization concerns numbers. If the biological system just described remains balanced, no single group of animals or plants may become excessively numerous, otherwise, the dominant group would quickly run out of food and starve, until the balance was restored.

Thirdly, water supports an immense variety of animals and plants. Every available kind of place is occupied by one or more creatures that are adapted to live there. Let us now look at a few selected organisms, starting with the plants.

ALGAE IN RECEIVING STREAMS

The algae are simple plants without true roots, stems, leaves or flowers. One of the smallest has already been mentioned - *Chlorella*. It is a minute, drifting, spherical plant that when magnified a hundred times is no bigger than a pin-head! *Cladophora* is a large alga that can be seen with the naked eye. It grows in long strands attached to rocks and so live in fast-flowing rivers and along exposed shores. It has become a nuisance along the coast line of Lake

Ontario because it grows abundantly and smells foul when it dies.

Among aquatic flowering plants we will only mention two, the water lily and the duckweed. The water lily is one of the largest aquatic plants and may be rooted in water twenty feet deep. The little floating duckweed in contrast is less than a quarter of an inch across and is the smallest flowering plant known to Science.

ANIMAL LIFE IN RECEIVING STREAMS

Animals are equally varied. Paramecium is microscopic and feeds on bacteria. Mosquito larvae breathe air and are usually seen hanging by their breathing tubes from the surface film of stagnant water. Blackfly larvae, on the other hand, are anchored to rocks in fast-flowing streams and absorb oxygen dissolved in the water. Crayfish are scavengers that clamber about on the bottom of lakes and rivers. The only animals that can move around freely are the fish, and even they tend to specialize by living in water of a certain depth or a preferred temperature.

Finally, bacteria may be found everywhere, some breathing oxygen, some doing without, some causing disease in animals, others breaking down dead bodies, some able to turn the nitrogen of the air into nitrate fertilizer.

CHANGES DUE TO SANITARY WASTES

Let us now consider what happens to waters that receive sanitary wastes, noting as before our three general headings; the balance of Nature, the number of individuals of each kind, and the variety of living things represented.

As creatures most sensitive to sanitary wastes become eliminated, the balance of Nature is disturbed. Those organisms that can tolerate the new conditions thrive and multiply so that the observer is impressed by the prominence of a few groups over the rest. The immense variety of organisms normally present is suppressed and the total

number of species is reduced. We will now see how this comes about.

Firstly, if any organic matter is discharged into receiving waters, it is broken down by bacteria. The bacteria use up oxygen the same as do nearly all other living things. The more organic matter that is present, the more bacteria are produced and the more oxygen is consumed. The discharge of sanitary wastes, therefore, reduces the concentration of oxygen in the water. If less than 5 ppm of oxygen remain, trout are eliminated. Most fish require 3 ppm of oxygen. If the oxygen concentration periodically sinks below 1 ppm, then only those organisms survive that can breathe air directly - or can do without oxygen for a time. Under anaerobic conditions, when there is no dissolved oxygen at all, the balance of Nature is drastically upset, the variety of living things greatly reduced and the number of individuals of each kind vastly increased. Under the worst conditions, all organisms are suppressed except sewage fungi, a few hardy air-breathing animals, and those bacteria that do not need free oxygen. As the fungi look like dirty cotton wool and these particular bacteria give off the characteristic odour of septic sewage, most people consider anaerobic conditions undesirable.

DUTIES OF SEWAGE PLANT OPERATOR IN PROTECTING STREAM

To avoid this situation, the duty of the sewage plant operator is clearly to keep the biochemical oxygen demand of his plant effluent low. A BOD of 10 ppm is sufficient to remove all the dissolved oxygen from the water once over: a BOD of 20 ppm will remove it twice over. It is especially important to avoid releasing slugs of wastewater with a very high BOD - a little spread over a longer period does less damage. What can live in a lake or stream is determined by the worst conditions that occur - even if they happen only on one day a year. It is worth noting too that the concentration of dissolved oxygen in receiving waters is usually lowest at night so that an effluent with a high BOD would do less harm during daylight.

The second effect of sanitary wastes on receiving waters is caused by a deposit of sludge blanketing the lake or river bottom. This may suffocate or bury living things, changing a highly productive area into a desert. Fish which feed on bottom-living organisms will starve. In addition, the buried animals and plants will die and produce a BOD of their own, causing a further deterioration.

It is clearly desirable to keep the concentration of suspended solids consistently low in the sewage effluent, and to avoid the sudden discharge of effluents high in solids.

OTHER EFFECTS OF SANITARY WASTES ON RECEIVING WATERS

The third effect of sanitary wastes is to add greatly to the fertility of the receiving waters. This leads to an increased development in the total mass of living things in the water. Algae especially grow in great profusion. This is not a matter for concern as long as they stay alive, but a time always comes - usually in late summer - when the algae will die. Then, in a few days, the enormous BOD of the dead algae depletes the oxygen and the resulting odour may be worse than the smell caused by the raw sewage in the first place.

A key element necessary for plant growth is phosphorous, and most fertilizers contain it. The activated sludge process converts organic phosphorous compounds into a soluble form, so that a well-treated sewage effluent is nothing more or less than a rather watery liquid fertilizer.

There is nothing, unfortunately, that the plant operator can do about this. A number of chemical methods are known whereby the phosphorous can be settled out of solution, but they are expensive. The development of a new, cheap method to reduce the phosphorous content in sewage effluents is urgently needed, so as to minimize the changes brought about by sanitary wastes in receiving waters.

CONCLUSION

Let us conclude by considering again the duties of the plant operator in the treatment of sewage. It is clear that his responsibilities do not end at the gate of the sewage plant; the success or failure of his works will be reflected in the changes his plant causes to the receiving waters. Not only must the effluent look nice and smell nice when it leaves the plant, but the rivers and lakes must look nice and smell nice after they have received it.

Finally, because plant operators are trained to recognize the changes brought about by the discharging of wastes, I suggest that you appoint yourselves as guardians of your respective watersheds and do your best to prevent other people from fouling your receiving waters. No one would wash his car and then let his children throw mud all over it. In the same way I suggest that you do your best to prevent other people from throwing their sanitary wastes around and so spoiling your effluent.

BACTERIOLOGY OF SEWAGE

L. T. Vlassoff
Supervisor, Bacteriology Branch
Division of Laboratories

INTRODUCTION

Prior to the middle of the 19th century, the sole objective of a sewage disposal system was to do just that - dispose of sewage to avoid the development of a nuisance. This is still an objective but more recently, attempts have been made to treat the material prior to disposal to remove both organic material (dissolved or suspended), and to eliminate disease producing agents such as bacteria, viruses and protozoa.

Human diseases are primarily transferred from man to man by his own infected fecal discharges and in some cases this is the only method of transfer. This disease transmission may be from feces to dust, to flies, to food or water, or to humans directly by contact. Water however has through the centuries played the foremost role in disease transmission. It is a matter of record that when proper water and sewage treatment facilities have been installed in a community, the health of its inhabitants has improved noticeably and their life-span has been extended.

Suffice it to say that floc formation and settling plays a large part in the removal of viruses and effluent chlorination diligently enforced removes bacteria, some viruses and other disease agents. It is not the intention of this lecture to discuss disease organisms however, although any lecture on the microbiology of sewage requires mention of these dangerous agents.

Another objective of a treatment system is to prevent the development of a nuisance condition by transforming dissolved and suspended organic materials into stable mineral compounds and cell contents. Bacteria are the principle agents active in these processes.

The decomposition of organic materials by bacteria is comparable to digestion in the intestine of animals. All digestive processes are brought about by micro-organisms in an effort to make use of the organic material as a source of energy or as building materials for microbial protoplasm. If this digestion takes place under aerobic conditions, the organic material may be oxidized to its end products or be assimilated into microbial tissue. If the conditions are anaerboic, it is impossible for the complete oxidation to take place and intermediate malodorous compounds may accumulate. Hydrogen sulphide, for example, ordinarily cannot undergo oxidation under anaerobic conditions. In the presence of oxygen, however, there are bacteria that readily and rapidly oxidize hydrogen sulphide to water and sulphuric acid, neither of which has any odour. (Chemical oxidation is, of course, also possible.) Therefore, all that is necessary in order to prevent the accumulation of disagreeable odour is to furnish organisms, decomposing waste materials, with adequate quantities of oxygen. This transformation of the easily decomposible organic materials into the end products of bacterial metabolism (that is to CO_2, H_2O, H_2SO_4, HNO_3, and so forth) is generally spoken of by the biologist as <u>mineralization</u> but is designated by the sanitary engineer as <u>stabilization</u>.

Without microbial activity, chemical break-down of sewage would be a very lengthy and costly process. Plant operation merely caters to the requisites of these micro-organisms and a study of bacterial activities should help to understand the treatment facility.

Micro-organisms in the sewage plant break down solids and remove dissolved materials from the liquid portion of sewage. They feed on sewage and waste substances in order to grow and reproduce, and as a result produce a nuisance-free effluent. The method by which microbial activity accomplishes this will be the main subject of the following discussion.

The nature of a bacterial cell must be considered to understand the enormous task that micro-organisms carry out. The composition of sewage is also important. This latter will be dealt with by others, and suffice it to say that a large portion of sewage is organic, i.e., it contains

a combination of carbohydrates (sugars), proteins and fats.

Bacterial metabolism and bacterial activity may be considered identical in meaning for this discussion. Bacterial metabolism, insofar as it involves biochemical changes taking place in sewage treatment, involves the intake, digestion and assimilation of food in and by the cells, and the transformation of the potential energy in food to kinetic energy with which the organisms accomplish work, and eliminate the waste products formed. More simply, metabolism is the study of the feeding habits of bacteria through which cells are formed, energy for life is obtained, and by which they eliminate their wastes. In general, metabolic processes may be divided into two categories, first, those involving constructive processes; second, those involving destructive processes. Constructive processes utilize energy; while destructive processes liberate energy. Within a bacterial cell, both of these processes take place at all times. The former must exceed the latter or otherwise growth can take place only at the expense of energy stored in the form of reserved food. It is well to keep in mind that the metabolism of most of the micro-organisms with which this discussion is concerned, differs little fundamentally from the metabolism of animals, including man.

Metabolic processes may be regarded in the following manner:

$$\underline{\text{Raw Materials}} + \text{Energy} \quad \underset{\text{destructive}}{\overset{\text{constructive}}{\underset{\text{enzymes}}{\rightleftharpoons}}} \quad \underline{\text{Food}} + \underline{\text{Waste Products}}$$

(CO_2, O_2, H_2O, NH_3, organic compounds,etc.		(stored sugars, starches, cellulose, tissue, cells, etc.)	(CO_2, O_2, H_2O, etc.)

WHERE DOES ORGANIC MATTER COME FROM

Plants containing chlorophyll,(the green colouring matter of higher plants) possess the peculiar property of being able to absorb radiant energy from the sun, utilizing it to carry out constructive processes to produce sugars which are stored in leaves. Simultaneously plants absorb water from the soil through their roots, and carbon dioxide from the atmosphere through the pores in their leaves. Through these compounds plants can further construct compounds from which fats, proteins, and other plant constituents are formed. Plants, therefore, are capable of producing organic matter in which the sun's energy is stored.

However, a plant must not be thought of as merely carrying out constructive processes resulting in the gradual accumulation and storage of potential energy in food. Liberation of stored energy through destructive changes is essential to all life processes and is taking place in the plant cells at all times. (This process of liberation is known as respiration.)

Animals derive the energy to carry out their constructive processes from potential energy stored in the organic food they eat. In this manner potential energy stored in plant and animal tissues ingested by animals will form further animal tissues, the net change resulting in an enormous change of stored energy.

BACTERIA

Bacteria have been defined as plants, though their metabolism more closely resembles that of animals. The majority of the better known bacteria derive their energy from the potential (stored) energy bound up in organic compounds. Most of the food utilized by bacteria is in the form of solids or dissolved organics. Bacteria possess no mechanism for ingesting solid material. Most animals are capable of taking into their digestive tracts solid foods and transforming them into a soluble state through the process of digestion. In the case of bacteria, the digestive process concerned in transforming insoluble foods into a

soluble condition must take place outside the organisms body. The chemical changes involved in digestion are the same whether they take place within or without the body of the organism. All such changes are accomplished through the intervention of so called "digestive juices" discharged within the digestive passages, or excreted into the surrounding medium. The active agencies in digestive juices are enzymes, that is, organic catalysts produced by the living cells. It is known that enzymes are destructive in their action, are sensitive to many acids, bases, salts and other compounds, and are easily affected by physical agents such as heat. The speed of change in composition of material attributable to enzymes depends upon the concentration of the enzyme. Enzymes are also known to be specific (for one type of molecular structure) in their reactions.

The action of extracellular and intercellular enzymes is somewhat different. The former are of value primarily in the activation of the reaction involved in changing insoluble foods into a soluble state, or reducing the size of the molecules of food so that they can readily "diffuse" into the cells. Intercellular enzymes continue the break-down of the molecule and in the process liberate energy and reduce the molecules to a size that can be used as building blocks in the construction of the organism's or cell's body.

BACTERIAL RESPIRATION

Respiration has been defined as those biochemical processes taking place in a living protoplasm, whereby energy is made available for life processes. This definition covers that phase of activity of an organism through which energy is obtained to carry on the process of growing and allow for the discharge of waste product. In higher plants and animals, the overall process is measured in terms of the uptake of oxygen (a raw material) and the liberation of carbon dioxide (a waste product). In this case, oxygen is presumably being utilized to bring about the oxidation of some food substances, whereby carbon dioxide is liberated and energy is made available to the organism to carry out its metabolism. (Early theories postulated that synthetic biological processes could

take place only through the intervention of atmospheric oxygen indicating that all organisms were classed as aerobic or needing oxygen to carry out their life processes. However, Louis Pasteur proved that bacteria could carry on their metabolic activities in the absence of free atmospheric oxygen. He proved that energy for synthetic processes of life could be derived from fermentative reactions under anaerobic conditions. More recently it has been shown that there are numerous respiratory processes which do not involve the utilization of molecular oxygen.) Nevertheless, most, if not all, of the energy liberating changes are basically oxidative (aerobic) in nature; as a result all such processes are frequently spoken of collectively as biological oxidation. Therefore microbial respiration is of paramount importance in all sewage treatment methods.

The biological changes involved in microbial respiration are exceedingly complex. To aid in gaining a mental picture of the process, numerous chemical reactions have been suggested, whereby the potential energy of various complex organic substances might be transformed into active energy for synthetic metalbolism. Most of these are too involved for a brief discussion of this nature. Suffice it to say that all respiratory processes are destructive in nature and that the general tendency is towards the transformation of organic compounds into the inorganic state, processes to which the term mineralization or stabilization has been applied.

UTILIZATION OF FOOD

Micro-organisms require food for the identical purposes that man does, namely, for growth and construction of new protoplasm, for repairing old worn out protoplasm, and for supplying energy with which to carry out these energy absorbing processes. Since the total mass of an individual bacterial cell is never very great, even under ideal growth conditions, the quantity of food required for this purpose is relatively small. However, the respiratory activity of an organism is more closely related to its external surface area than to its volume because of the location of extracellular enzymes. The ratio of surface

area to volume in bacteria is extremely wide. If we take surface area as a measure of activity - consider the following - a cubical organism 1 mm square would have a volume of 1 cubic mm with a surface area of 6 square mm, giving a ratio of surface to volume of 6. If this cubical organism were divided into cubical portions 1 micron on a side, there would still be 1 cubic mm of volume but the overall surface would be 6 billion square microns (or 6 thousand square mm) giving a ratio of surface volume of 6 thousand.

This situation exists in the spongy zoogleal masses. It is obvious that the exposed surface of this given volume of bacteria is thousands of times greater than that of an equal volume of macroscopic (larger) organisms. (1 micron = 1 over approximately 400 thousands of an inch.) It is this enormous exposure of surface with the corresponding high respiratory activity that enables micro-organisms to accomplish the marked changes that take place in sewage treatment during relatively short periods of time. As mentioned earlier, extracellular enzymes produced on the surface of bacterial cells would correspondingly be enormous in quantity.

The actual specific compounds that may be utilized as food by bacteria are almost unlimited. A statement has been made that every organic compound occurring naturally or produced biologically can be utilized as food by some microorganisms. If some provision for the destruction of organic matter were not made by nature, any such compound would gradually accumulate and the surface of the earth would eventually become so impregnated with it, that life in its present form might become impossible. The greater the variety of extraneous substances present in sewage, particularly of an organic nature, the larger the variety of microorganisms that will find suitable foods for growth. There are even specific groups in bacteria that are capable of utilizing substances ordinarily regarded as unavailable to any form of life, such as woods, parafins, ammonia, reduced iron, hydrogen sulphide, carbolic acid, methene, hydrogen, nitrous acid, and so on. These substances may function either as food for building or repair purposes, as a source of energy, or for both building and energy.

Organic materials found in sewage, such as vegetables, paper, wood, muscular tissue, and the like, are made up largely of very complex molecules of unknown composition. In the syntheses of these complex molecules by the plant or animal, they are not built up directly from the elements but are assembled from less complex molecules. Just as the smallest train is assembled from two single cars coupled together, so ordinary table sugar is assembled in sugar cane from two molecules of simple sugars. Carrying the simile further, just as the train may be made up of hundreds of individual cars, all of which may or may not be alike, similarly a complex organic molecule may be made up of hundreds of individual molecules of a sugar or of other comparatively simple molecules, all of which may or may not be alike.

Making further use of the above simile, the train of a hundred cars may be uncoupled between any two cars forming a number of smaller trains of equal or unequal size. Similarly a complex molecule composed of hundreds of molecules can be split up into equal or unequal units each forming a complete molecule. This, in brief, is all that the micro-organism (through the agency of enzymes) does in splitting up complex molecules into simpler ones, or in bringing about the initial steps in the decomposition of organic matter. After the complex molecules have been split into small enough units, they become soluble and then can be utilized in the metabolism of the micro-organism.

Since enzymes are specific to a particular biochemical change, the organism must produce a special enzyme to catalyse each chemical reaction. In the human body, the groups of specialized cells known as glands are gathered together to produce these enzymes. Each gland produces a certain set of enzymes to carry out a particular biochemical change. In the microbial or bacterial body, the single cell must produce all of the different kinds of enzymes necessary in the metabolism of the organism. Since all biochemical changes are the result of intervention of enzymes, it is possible for micro-organisms to bring about chemical changes at a temperature of about 20°C. that cannot otherwise be induced at temperatures below 100°C. by chemical reaction alone without enzymatic products.

THE COMPOSITION OF CARBOHYDRATES

Carbohydrates, or sugars, or organic compounds that are composed of carbon, hydrogen and oxygen, make up a greater part of the organic material of plant origin and hence are a major constituent of the organic matter in sewage. Cellulose, a complex molecule, composed of many glucose (sugar) molecules, grouped together, is the most abundant carbohydrate found in sewage. Cellulose, for example, is insoluble and cannot be readily used by micro-organisms unless it is broken down into its component sugars which are soluble. Therefore, extra-cellular enzymes are produced by the micro-organisms to react with cellulose to break it down into a compound called cellobiose which in turn is broken down into glucose molecules which are soluble and become available for the metabolism or nutrition of the surrounding micro-organisms. We see, therefore, that the primary digestive enzymes in microbial decomposition are secreted by bacteria and break down the molecular structure of food (sewage) outside the cell. Up to this point in decomposition, virtually no actual destruction of organic matter has taken place, though there has been a reduction in particle size, and little or no oxygen has been used up in the processes involved.

When the sugar molecule is absorbed into the microbial cell from the surrounding solution, it immediately undergoes complex thermo-chemical alterations, whereby the potential energy of the molecule is transferred into active or kinetic energy necessary for bacterial life processes. A small portion of the sugar in the form of some decomposition product may be utilized by the organism for building and repair purposes, but the major portion functions as a source of energy. This transfer of stored energy in the ingested foods, to kinetic energy to be utilized by the microbial body, is most efficent when it involves aerobic (oxygen requiring) respiration. This is why free atmospheric oxygen is essential in the life processes of aerobic organisms. Similar reactions take place with other carbohydrates existing in sewage.

The composition of fat, oils, waxes and the like, although of a different structure, eventually undergo the same steps in the decomposition, whereby the molecules

become smaller and smaller until eventually they may be either oxidized to the final product carbon dioxide and water, or resynthesized into microbial tissue. Here again the basic changes involved are identical to those taking place in the alimentary tract of body tissue of man.

DECOMPOSITION OF PROTEINS

The third of the major groups of organic compounds found in (food) sewage, are proteins. Proteins differ in elementary analyses in that they contain both nitrogen and sulphur and sometimes phosphorous in addition to carbon, hydrogen and oxygen. Proteins are present to a limited extent in all plant and animal tissue and are abundant in muscular or lean meat tissue and in seeds of certain plants, particularly in the legumes. Proteins like carbohydrates and fats are not synthezied directly from the elements but are assembled from other complete molecules.

The protein molecule is usually very large being composed of the variable number of different amino acids. Some proteins are soluble but even the molecules of these are too large to diffuse through membrane of the microbial cell. Consequently, they cannot be absorbed by living organisms without primary splitting of the complex molecule. The enzymatic stages involved here are similar to those mentioned in detail in the section under The Composition of Carbohydrates. The end products of complete oxidation of proteins are carbon dioxide, water, nitric and sulphuric acid, and also phosphoric acid where phosphorous is present.

SUMMARY

1. Sewage treatment is biochemical in character and micro-organisms are the active agents in the mineralization of solids and dissolved solids.

2. The mechanism which enables a rapid mineralization of wastes at normal temperatures is the enzyme system.

3. Extracellular enzymes of organisms aid in the breakdown of solids into soluble particles.

4. Intercellular enzymes of organisms use the solublized substances to build cell body materials and stable compounds in the presence of oxygen.

5. All treatment processes merely cater to microbial activity.

6. Micro-organisms are not acting in a special way in sewage treatment, but are merely doing the job for which they were intended.

CHEMISTRY OF SEWAGE TREATMENT AND INTERPRETATION OF ANALYTICAL RESULTS

C. E. Simpson
Supervisor, Chemistry I Branch
Division of Laboratories

In the course of domestic and industrial use of the municipal water, the waste products added to it increase both the dissolved and the suspended solid content. Both these increases consist of partly inorganic and partly organic matter. There is a distinction between the relatively inert and inoffensive inorganic or "ash" content of sewage, which passes through a treatment plant largely unchanged, and the putrescible organic content which must be removed by treatment, and converted to inoffensive end products.

ORGANIC COMPOUNDS

Organic compounds, those which contain carbon and which are involved in the chemistry of living organisms, are many times more numerous than all the compounds formed by all the other 91 or so elements. The study of carbon compounds, 'Organic Chemistry', is by itself one of the major branches of chemistry.

The organic chemicals present in sewage are mainly the by-products of food preparation together with the partly decomposed residues of food, and as such, fall into the same categories as does food; proteins, carbohydrates and fat. These natural food chemicals are susceptible to natural decomposition processes - 'Biological oxidation'. When organized and given a suitable environment, sufficient air supply, intimate mixing, etc., these natural processes form the basis of the biological sewage treatment plant, whether it be activated sludge, trickling filter or oxidation lagoon. It is well to note that through the multiplying use of synthetic organic chemicals, increased amounts of these materials are being discharged as waste. Many of these are not susceptible to present biological treatment processes and pass through such plants largely unchanged. New treatment methods are being sought which will remove or break

down these resistant chemicals.

An example of which you have all heard is detergents. The chemical 'surfactants' which used to form the active or suds producing portion of these formulas were of a type which could only be partially reduced in concentration by biological treatment and thus they passed through to the receiving water in the same fashion as do the soluble inorganics. This problem has now been overcome by the substitution of 'biodegradable' surfactants which can be broken down by sewage treatment processes to a greater degree. A solution to the greater problem of the high phosphorus content of detergents has not yet been found.

Returning to the food type chemicals which <u>can</u> be removed, carbohydrates, fats and proteins, let us use the same dodge the chemist resorts to, in order to visualize their structure. It is possible to draw diagrams of the way these molecules are formed from atoms, similar to the way a house is constructed from various bricks. In organic chemistry the 'bricks' are individual atoms and small groups of atoms. Carbon is represented by $-\overset{|}{\underset{|}{C}}-$, the four bars show it can combine or 'bond' with other atoms in four directions, (like mortar). Similarly oxygen is -O- with two bonds. Hydrogen is H- with one bond. Nitrogen N can have either 3 or 5 bonds. Using these symbols,

Water, H_2O, is represented by $H - O - H$

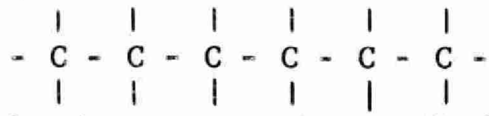
Methane, CH_4, by
$$\begin{array}{ccccc} & & H & & \\ & & | & & \\ H & - & C & - & H \\ & & | & & \\ & & H & & \end{array}$$

Ethane, C_2H_6,
$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ H & - & C & - & C & - & H \\ & & | & & | & & \\ & & H & & H & & \end{array}$$

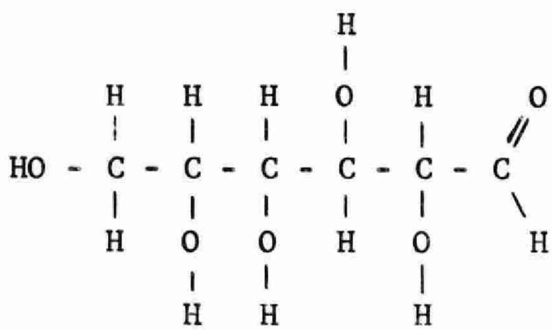
Carbon dioxide, CO_2, is $O = C = O$ in which the bonds are paired or "double bonds".

CARBOHYDRATES

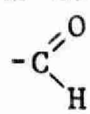
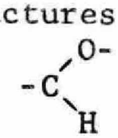
Carbohydrates are huge chemical structures formed from groups of individual sugar compounds which in turn are formed from carbon, hydrogen and oxygen, much as apartment houses are made up of individual two, three or four-bedroom suites, which in turn are constructed of bricks. For example, ordinary glucose $C_6H_{12}O_6$, has a long chain of 6 carbons joined together.



Onto the extra bonds are attached - OH (hydroxyl)
= O (Oxygen)
and - H (Hydrogen) groups



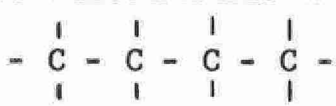
Different individual sugars are formed merely by a change in the placement of the OH groups, or by the presence of fewer or more carbon atoms in the chain.

These individual sugars (apartment suites) are linked together to form large molecules or structures through the  group which is changed to , the open bond attaching to a carbon in the next sugar molecule. Starches are formed of 13 - 15 individual sugars linked in this manner.

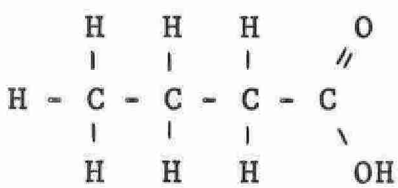
The name carbohydrates is given to these compounds because, overall, they appear to be a combination of water and carbon, (hydrated carbon or carbohydrates). For each C atom there is one water, H_2O. In glucose, $C_6H_{12}O_6$ there are 6 Carbon, 12 Hydrogen, and 6 Oxygen atoms, or 6C, $6H_2O$. During oxidation, 12 more Oxygen atoms are needed to form the final end products 6 CO_2 and 6 H_2O (carbon dioxide and water).

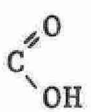
FATS

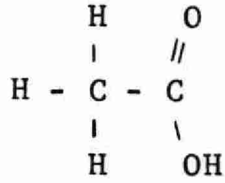
Similarly, fats are constructed of individual fatty acid groups. For example, a fatty acid with 4 carbon atoms is butyric acid. This has an offensive odour and is found in rancid butter, in cabbage and similar strong smelling vegetables, and in digesters as part of the volatile acids. The four carbon atoms are again in a chain -



In this case only there are more H and less OH attached to the bonds.



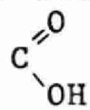
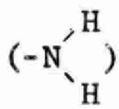
The  is the characteristic 'acid' part of all organic acid compounds. Various fatty acids occur each with more or fewer  in the chain. Those found in animal fats, suet, etc. have a very long carbon chain, as many as 15 or 17 carbon atoms joined together, (with hydrogens attached also, of course). One of the shorter ones with only two

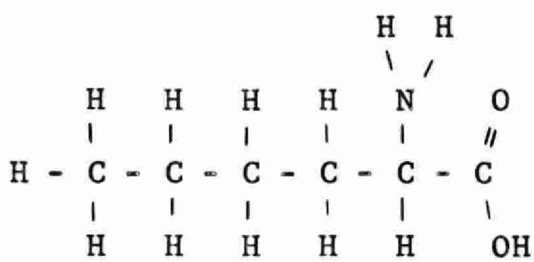
carbon atoms  , is acetic acid, the acid found in vinegar.

During oxidation, because of their low oxygen content (only two O atoms per fatty acid molecule), more oxygen is required to finally produce the CO_2 and H_2O end products. For example, caproic acid which contains 6 carbons $C_6H_{12}O_2$ would require 16 oxygen atoms to form CO_2 and H_2O (whereas glucose requires only 12).

Three of these individual fatty acids are linked together through the - C - O - H group, with one molecule of glycerine to form a complete structure, a fat.

PROTEINS

The proteins as well as containing C, H, O, have N atoms in the structure. The 'apartment suite' sized compounds are called amino acids and again have a carbon chain and a  acid group, but in addition have an amino NH_2  group tacked on. For example, Norleucine with 6 carbon atoms $C_6H_{13}O_2N$.



*(___)

Another type of variation among organic compounds is shown by two other amino acids which are very similar to, but still distinctly different, from Norleucine.

```
                                    H H
                                    \ /
                    H   H   H   N    O
                    |   |   |   |    //
Leucine       H - C - C - C - C - C
                    |   \   |   |    \
                    H       H   H    OH
                     H-C-H
                       |
                    *(__H__)
```

```
                                    H H
                                    \ /
                    H   H   H   N    O
                    |   |   |   |    //
Isoleucine    H - C - C - C - C - C
                    |   |   \   |    \
                    H   H       H    OH
                         H-C-H
                           |
                        *(__H__)
```

There are 24 amino acids found in proteins, which are very complex structures formed of many hundreds of these amino acids joined together, between the - C-O-H of one and the

```
  H
 /
-N
 \
  H  of the next.
```

Again proteins require more oxygen than do carbohydrates during the breakdown to oxidized end products CO_2, H_2O, NO_3. In the case of leucine, 19.5 oxygen atoms are needed. (only 15. if NH_3 is formed)

It is hoped that the above, while rather technical will serve to demonstrate first, why there are so many organic compounds, since a change merely in the placement of

an atom creates an entirely different compound, and secondly, why so much oxygen is required to break these organic compounds down. I wish to avoid creating the impression, however, that this breakdown is accomplished just by 'lopping' the organic molecules into fragments and combining them with extra oxygen. This is the way a flame destroys organic compounds. The living bacteria and other organisms which oxidize these organic materials during sewage treatment do so very gradually, passing the molecule through a long series of subtle alterations before even as much as one carbon atom is converted to CO_2. The study of these complex living chemical reactions is called Biochemistry. Once again though, the <u>eventual</u> end products of biological oxidation are CO_2 and H_2O.

These organic compounds are your main concern in treatment. The dissolved inorganic matter or ash, which, from a biological oxidation viewpoint is inert, passes through your plant without much you can do about it. Luckily, apart from their fertilizer value, these minerals do not usually have much adverse effect on the receiving water. Fail to remove the organic content, though, and your stream is in trouble. The oxidation that didn't get completed in the plant take place in the stream, its dissolved oxygen will drop and you may have a fish kill and a stench problem.

Turning now to the quantities of this material you have to deal with, and the trends which take place during treatment, we come to the measurement of solid matter in water. This is classified by tests as follows.

SOLIDS TESTS

Dried Solids

This is the weight of the dried residue from a measured quantity of sample from which the 'free' water has been driven off in an oven at 105°C (220°F), just above the boiling point of water. But there is still a small quantity of 'combined' water present. This is firmly combined in the residue, and can only be removed by higher temperatures. If

this is attempted, some of the solid residue breaks down and is lost, so it has been agreed that 103 - 105°C is the best temperature for drying solids. One must remember though that a variable part, possibly 5 per cent, of this value is water. This combined water is held in the residue similarly to the way dry lime cakes and hardens in moist air to form slaked lime which still appears quite dry. It is necessary to calcine the lime again to remove this 'combined' moisture.

Ash

If the dried residue is heated to 600°C (about 1100°F) and allowed to burn, the organic matter is oxidized to carbon dioxide and water and is lost, or volatilized. The residue is the mineral ash.

Volatile Solids

The loss in weight at 600°C includes not only the organic matter in the sample, but the 'combined' water, and in addition some of the mineral matter, a portion of which breaks down, especially chlorides, carbonates and nitrates.

Thus the Volatile Solids is always slightly greater than the actual organic content and the Dried Solids more than the actual 'anhydrous' or water free weight.

FORMS OF SOLIDS

The solids in water can also be classified by their physical state.

Suspended Solids

This is measured by filtration through very retentive, fine pore filters. The recommended type is the Gooch filter which uses a thick pad of asbestos. Even this does not retain <u>all</u> the fine particles and the filtered liquid is often still slightly hazy. 'Suspended' solids is

now being called 'Non-Filtrable' solids which more accurately defines the result. Non-Filtrable or suspended solids can be classified further into settleable solids, and non-settleable suspended solids, commonly termed 'colloidal' because of its small particle size.

Dissolved Solids

Now called 'Filtrable Solids'. This measures the soluble solids which are in true solution and as well, may include small amounts of the finest suspended matter which show as the haziness noted above, after filtration.

Combining the two classifications, representative values for a strong raw sewage, in ppm are:

	Total	Suspended	Dissolved
Dried	1,000	300	700
Ash	600	100	500
Volatile	400	200	200

EFFECT OF TREATMENT ON SOLIDS VALUES

Starting with the Municipal water, solids are present (or should be) only in dissolved form, with no suspended matter. It is impossible to quote a single representative figure since Ontario has two distinct varieties of water. Soft, lightly mineralized waters are obtained from the northern and eastern hard rock areas, since hard rock is almost completely resistent to solution by water. In the southern area the soils contain limestone which is soluble in rain water to an appreciable degree, the water is hard, with higher dissolved solids. Therefore, two figures are quoted (see tabulation).

Note that, on the average, 10 per cent of these dissolved mineral solids is lost on ignition, representing the 'combined' water and the mineral material which is lost at 600°C. Where the water supply contains dissolved organic

	BOD ppm	DRIED Suspended ppm	DRIED Dissolved Soft ppm	DRIED Dissolved Hard ppm	SUSPENDED Proportions as % Ash	SUSPENDED Proportions as % Volatile	DISSOLVED Proportions as % Ash	DISSOLVED Proportions as % Volatile
Municipal Water	1-2	0	100	400	0%	0%	90%	10%
Raw Sewage	250	250	300	600	30%	70%	65%	35%
Primary Effluent	170	80	300	600	30%	70%	65%	35%
Final Effluent	15	15	250	550	-	-	80%	20%
Primary Sludge	- (high)	60,000 (4% up to 10%)	-	-	30%	70%	-	-
Activated Sludge	- (high)	very variable (2% to 5%)	-	-	25%	75%		
Combined Sludge	- (high)	40,000 (2% to 8%)	-	-	25-30%	70-75%		
Digested Sludge	(lower)	50,-100,000 (5% to 10%)	-	-	50%	50%		
Supernatant	(high)	preferably clear	2,000		40%	60%		

material as well, as in many surface waters, the per cent volatile matter may be raised from a low of 5 per cent up to 25 per cent.

On the average, these municipal waters after domestic use, pick up about 250 ppm suspended matter and about 200 ppm dissolved solids, which raises the original dissolved solid content. Figures quoted as representative vary markedly from plant to plant, and even in the same plant from time to time. Variations may run from 3 times less to 3 times greater, a range of about 1,000 per cent. So, these average values will range much higher and lower through one day as the activity of your citizens proceeds through its daily cycle. This is why 8 hour averages can be so misleading.

The dissolved solids may be much higher in some cases. Industrial discharges often boost the dissolved solids as much as 400 - 500 ppm. Fortunately the suspended solids and BOD do not always increase in proportion, usually rising only 100 or 150 up to a total of 350 or 400. Operators at combined sewage plants are likely to notice abrupt increases in the dissolved solids (as well as in the flow) when thaws or snowfalls occur during the winter. These dissolved solids increases result from salt spread on the streets, and are expecially pronounced during the final March thaws.

Of the 250 ppm average suspended solids, about 1/3 (80 ppm) is ash and 2/3 (170 ppm) is volatile solids of which possibly only 150 ppm is organic, when allowance is made for the other volatile losses. The same proportion holds true for the primary sludge; 1/3 ash, 2/3 volatile, although since the settleable solids have been concentrated by compaction, the concentrations are much higher. For an average sludge of 6 per cent solids (60,000 ppm,range 4 to 10 per cent) the ash would be around 20,000 ppm or slightly less, the volatile content about 40,000 ppm or slightly more. Thus there is no change in these proportions in the primary effluent.

Removal of the settleable solids by primary sedimentation usually reduces the suspended solids about 30 per cent, often more.

The remainder of the suspended solids, that is, the non-settleable or 'colloidal' portion, and all the dissolved solids pass through to secondary treatment. Thus the dissolved solids concentration is the same as in the raw. These remaining portions of the refuse originally added to the water, still retain the major proportion (about 2/3) of the BOD of the original waste. This has yet to be removed to provide an acceptable effluent.

This is accomplished in two ways, through biological oxidation. The first is by intimate mixing with the active agents, the activated sludge or the trickling filter slimes, which actually trap and physically remove both these suspended and dissolved organic materials. This takes place by a complex biological action which is even now not thoroughly understood. On a chemical basis, the iron and alumina which make up the main part of the inorganic content of sludge have the property of flocculating to form a fluffy fibrous mass. It is thought this is the 'backbone' of the floc which attracts and traps both further iron and alumina, and colloidal organic matter. The gelatinous organic material which makes up 2/3 of the weight of the sludge acts in the same way to physically trap the colloids. At the same time, the living organisms absorb dissolved organic material, grow and multiply, hence, they trap this dissolved organic matter as part of their tissue.

Secondly, some of the organic material absorbed by these organisms is oxidized to the end products mentioned previously, CO_2, H_2O, (possibly NO_3), the first of which passes off as a gas. This oxidizing effect continues as long as the sludge is kept aerobic.

Thus the organic and the suspended solids content can be reduced to acceptable levels in the final effluent, although the dissolved solids in the discharge is always increased over that of the original water through the addition of both inert and oxidized soluble mineral matter.

Returning to the sludge, the oxidation of the organic content continues as long as the sludge is kept aerobic. The basis of the 'Total Oxidation' theory is to supply sufficient retention time to allow this oxidation to

proceed to completion, avoiding sludge digestion.

When anaerobic digestion is begun the organic content of the sludge is converted, again by bacterial agents, but of a different type, to completely different end products. These bacteria still require oxygen in order to live, but since there is no dissolved or gaseous oxygen they have developed the ability to hang onto every atom of oxygen they can obtain. Oxygen can be derived from their food, which always contains appreciable quantities in chemical combination in the organic matter, which as shown before contains Carbon, Hydrogen, Oxygen, Nitrogen and in addition some Sulphur, 'S', Phosphates, 'P', etc.

The end products of this miserly attitude toward oxygen show a substitution of hydrogen insofar as possible. Thus carbon appears as methane gas (CH_4). Nitrogen appears as free gaseous N, or as ammonia (NH_3). Thus the organisms pick up oxygen from any NO_3 which may have been present. In addition, the necessity of using oxygen to form water from the hydrogen, is avoided.

Sulphates (SO_4) or organic sulphur compounds may be converted to (H_2S) hydrogen sulphide, 'rotten-egg gas', one of the culprits which produce the obnoxious odour of putrescence.

These anaerobic bacteria release as little oxygen in the form of CO_2 or (H_2O) as is necessary for respiration and survival.

Through the release of digester gas, containing CO_2, CH_4, N, the organic content of the combined sludges is decreased, and the sludge becomes much less offensive and bulky.

Because of the reduction in volatile organic matter, the mineral or ash content (which never disappears) forms a larger proportion of the sludge, roughly 50%/50%.

The supernatant, and hence all drainage from sludge, still contains very high concentrations of dissolved (if not of suspended) solids, of which an appreciable quantity is organic, and must be returned to the plant for further treatment.

LABORATORY CONTROL AT SEWAGE TREATMENT PLANTS

J. M. Timko

District Engineer,
Division of Sanitary Engineering.

INTRODUCTION

A sewage treatment plant like any piece of machinery must be properly operated if it is to produce optimum results. A mechanic performs certain tests on an automobile to ensure that it runs properly and to diagnose and intercept problems. A doctor must perform tests to diagnose a disease or to anticipate an illness before it becomes too far advanced. Similarly the sewage treatment plant operator can perform certain tests to determine how well the plant is operating, anticipate problems before they become too pronounced, or to diagnose existing problems.

There are, of course, many tests which can be performed depending on the amount and sophistication of the equipment available and the experience and time of the operating staff. Laboratory control under the scope of this paper will be limited to those tests which can be performed regularly at the plant itself, by the operator. Other necessary tests can be performed on a less frequent basis by the OWRC laboratory.

RECORDS

An important factor, often overlooked, yet of extreme importance, is the recording of the data resulting from the daily operational tests. By keeping records of plant test data, patterns in sewage quality can be established and problems can be anticipated before they become critical. Evaluation of plant performance as outlined by records of the daily operational tests can figure prominently in decisions regarding the need for, and extent of, plant enlargement. Lastly, by recording and interpreting the results of the operational tests regularly, the operator can gain a deeper insight into the operation of the plant, the processess involved and in turn make his job more interesting and challenging.

SOLIDS DETERMINATION

In the practical operation of sewage treatment plants, the settleability of the sludge is an important factor. Variation of the mixed liquor concentration is the most flexible method of controlling activated sludge quality. By increasing or decreasing the amount of sludge carried, the food to micro-organism ratio can be controlled and maintained at the value which gives the best operating balance.

To control the mixed liquor loading, it is necessary to measure the suspended solids in the aeration tank and the settleability of the mixed liquor. This can be done at the plant by means of the centrifuge test and the thirty minute settling test.

Centrifuge Test

The total dry weight of the suspended solids can be determined by filtering, heating and weighing in a laboratory, or from a centrifuge calibration curve. The laboratory method of course, provides the most accurate determination of suspended solids value. However, this procedure is long and involved, and requires rather sophisticated equipment not often available at most treatment plants. The centrifuge test has the advantage that it is easy and quick to perform and does not require much equipment other than a centrifuge which is readily available and inexpensive.

The standard centrifuge used at sewage treatment plants is equipped with two 15 ml graduated tubes. The test is carried out by filling both tubes up to the mark with a sample from the aeration tank effluent. The centrifuge is then turned on and operated at a speed in the order of 1500 to 1800 rpm for three to five minutes. Whichever combination of centrifuge speed and time is used, it is very important for uniform results that the centrifuge is always operated at the same speed for the same length of time.

It is also important that the sample is well mixed and the 15 ml tubes are filled in the same manor each time the test is performed. The samples should be collected from the same point in the aeration tanks at the same time each day.

To use the centrifuge test in plant control, it is necessary to have available a centrifuge vs suspended solids graph. Since sewage characteristics, loading conditions, and flows vary at all plants, the mixed liquor suspended solids characteristics will also vary at each plant. Therefore, it is advisable to prepare a specific graph for each specific plant.

This is done by collecting a different number of duplicate mixed liquor samples at different times, under different loading conditions, and determining the suspended solids by weight in the laboratory and by volume utilizing the centrifuge. The suspended solids by weight can be determined by sending the sample to the OWRC laboratory for analyses. The test results from each sample are then plotted on graph paper, and a line drawn to best approximate the plotted points.

Once this graph has been prepared the suspended solids value for subsequent samples can be obtained by merely performing a centrifuge test on the sample of mixed liquor and reading the corresponding value for suspended solids off the plant graph.

A typical centrifuge vs suspended solids graph is appended.

Thirty Minute Settling Test

This test is performed on a sample of the mixed liquor from the effluent of the aeration tank. The sample should be taken with as little agitation as possible. The test procedure consists of gently filling to the mark, a 1000 ml graduated cylinder. The contents of the cylinder are allowed to settle for thirty minutes and the volume occupied by the settled sludge is read off.

To merely conduct a settling and centrifuge test however, is not sufficient, as there must also be some knowledge of the density of the sludge. The relationship of volume to weight, or density is important in determining the condition of the sludge.

The sludge volume index is the volume in millilitres (ml) occupied by 1 gram (gm) of sludge after settling for thirty minutes. The formula for making the calculation is as follows:

$$\text{SVI} = \frac{\text{per cent settleable solids (thirty settling tests) X 10,000}}{\text{ppm suspended solids (aeration tank)}}$$

The sludge volume index expressed as per cent solids is the sludge density index.

$$SDI = \frac{100}{SVI}$$

The level at which these values should be maintained and their significance in other operations will be discussed in detail by other lecturers. In general, bulking sludge that will not settle and is not suitable for return to the aeration tanks will have a high SVI, (200 or even higher). A low index of 40 would give a fast settling sludge, however, clarification is generally not the best at these low levels. An index of around 100 would be average.

Frequency and Testing

The above tests should be performed on a minimum of at least once daily and preferably in the afternoon. In order to have a consistent correlation of results they should be conducted on samples taken from the same place at the same time each day. However, interesting differences can be noted if the tests are performed several times during the day rather than only once. It is suggested that on a few occasions the tests be made throughout the day at one hour intervals and the results recorded and plotted.

DISSOLVED OXYGEN TEST

Interpretation

The breaking down or decomposition of the organic solids in sewage can proceed in either of two ways.

1. In the presence of a supply of oxygen dissolved in the accompanying water, known as aerobic decomposition.

2. In the absence of oxygen or, as it is termed by anaerobic decomposition.

The end products of both processes are generally similar, in that stable, inorganic, substances result, which are not subject to further breakdown. However, during the process there are created considerably different conditions. In the

anaerobic or septic process foul odours such as H_2S (hydrogen sulphide) are created and the sewage has an unsightly appearance. When the breakdown occurs in the presence of oxygen, these unpleasant conditions do not occur and the reduction of organic matter continues in a more orderly manner.

When sewage, raw or treated, is discharged into a stream there is a drop in the dissolved oxygen content of the receiving water. Depending on the use of the stream, the level to which the dissolved oxygen drops is very important. The following table will give some guide as to the dissolved oxygen required for different types of streams.

Stream Use	Necessary Level of Dissolved Oxygen
For game fish	above 5.0 ppm
For coarse fish	above 3.0 ppm
To prevent nuisance conditions	above 0.0 ppm

These levels should be present under maximum conditions which generally occur at night or early dawn, when the dissolved oxygen in the stream is at its lowest value.

In raw sewage the dissolved oxygen level will vary depending on the existing conditions. The level will decrease, with heat as during the summer, as the flow in the sewers decreases and deposited solids in the sewers become septic, or as the travel time to the plant is increased, i.e. an extension of the sewer system. The oxygen level will rise as the flow increases due to storm water flow or ground water infiltration. Where sewer grades are good, a dissolved oxygen level of 4.0 to 6.0 ppm is common for average municipalities. In some areas however, such as Kent and Essex Counties, where the sewer grades are at a minimum because of a very flat terrain, it is not uncommon in the summer to have raw sewage with a dissolved oxygen content below 1.0 ppm.

The operator should take enough dissolved oxygen tests on the raw sewage at his plant to establish trends for the various seasons and weather conditions. Variations in the established patterns should be investigated.

In the activated sludge process, a dissolved oxygen level above 2.0 ppm and generally below 5.0 ppm should be maintained in the aeration tanks. It sometimes is not possible to

maintain the minimum level immediately adjacent to the inlet. The necessary level of oxygen to be maintained at the inlet will depend to some degree on the efficiency of the sludge collection and recirculation from the final settling tank. That is, where sludge remains for long periods of time in the final settling tank it will be necessary to have a higher oxygen content in the aeration tanks. This will reduce the possibility of septicity in the recirculated sludge. When too much air is added the sludge becomes nitrified, gas is produced and a poor settling floc results.

The amount of oxygen that can be dissolved in water varies with temperature. At a temperature near freezing, water will contain 14.5 ppm oxygen at 100% saturation, whereas at 60°F it will contain only 9.2 ppm of oxygen, at 100% saturation. It is therefore, important to take temperature readings at the time of the test. The test result can either be given as parts per million or per cent saturation.

A number of different methods have been developed for determining the dissolved oxygen content of sewage. The method selected for use must be one which will produce accurate results and eliminate the effect of any interfering materials present. Most tests are a modification of the Winkler Method. The one most frequently used in sewage treatment plants is the Alsterberg modification of the Winkler test. This test as well as the various modifications to compensate for interfering substances are all outlined in "Standard Methods For The Examination Of Water and Waste Water" prepared and published jointly by the A.P.H.A., AWWA., and the WPCP.

A simpler test for measuring dissolved oxygen is by the Miller Method. This is reasonably accurate except at the lower levels, i.e. around 1.5 ppm. At this value it generally gives a higher value to the dissolved oxygen reading.

To measure the dissolved oxygen content in the aeration tank the test is performed on grab samples and must be done at the time of sampling. Extreme care must be exercised in collecting the sample and carrying out the test to make sure that oxygen is not artificially introduced into the sample.

Another method for measuring dissolved oxygen levels which is becoming more prominent is through the use of the dissolved oxygen probe. In recent years a number of variations of the dissolved oxygen probe principal have been developed. These all consist essentially of an electrical method for providing

a direct reading of the dissolved oxygen level simply by insertion of a probe into the liquid and measuring the associated electrical current increase or decrease in a polorographic or galvanic probe. However, there are a number of problems with the use of this device due to the need for constant cleaning and calibration of the equipment and associated problems. Temperature also can severely affect readings. However, with advances in technology this will probably become a common method of measuring dissolved oxygen in the near future.

Where facilities and personnel permit, testing should be performed daily. Tests should be made on the raw sewage, plant effluent, aeration tank effluent, and return sludge. In smaller plants these tests can be performed less frequently once a pattern is established.

The Rawson nomogram for obtaining oxygen saturation values at different temperatures is appended to this lecture.

CHLORINE RESIDUAL

Chlorine is used at sewage treatment plants for the disinfection of effluent, odour control, to reduce bulking in activated sludge plants and control the development of flies in trickling filters.

Some organisms in sewage can survive even complete treatment processes ; chlorine should be added to the final effluent to kill these organisms and check the spread of disease. This is particularly important in areas where the downstream water is used for drinking purposes, shell fish culture and recreational activities.

Residual chlorine may exist in one of two forms; either free residual chlorine, i.e., hypochlorite ions, or as combined residual chlorine, i.e., in combination with ammonia as chloramines or with certain nitrogenous compounds as organic chloramines. There are large numbers of chlorine absorbing material in sewage, therefore, free chlorine is seldom found.

To kill organisms with chlorine it is necessary to provide both a definite concentration of chlorine and to expose the organisms to this for a length of time. The Commission's requirements are that there be a chlorine residual of 0.5 parts per million after 15 minutes contact between the chlorine and the sewage.

The amount of chlorine applied to produce the above residual varies with different conditions and sewages. The following is an indication of the dosages which may be needed to produce a residual of 0.5 ppm.

Type of Treatment	Chlorine Dosage
Seconday treatment effluent	5.0 ppm
Primary treatment effluent	15.0 ppm
Raw sewage	25.0 ppm

The chlorine feed rate for an effluent will vary as to the flow and the quality. More chlorine will have to be applied as the flow increases and as the quality of the effluent deteriorates. Therefore, it is necessary to take frequent residual tests throughout the day until the operator establishes a definite pattern. It then may be necessary to only take one or two tests each day. In any case, an adequate residual should be maintained at all times.

There are various methods of testing but the one that is most frequently used is the orthotolódine test. Coloured solutions can be made up for this test but a more satisfactory method is to purchase the permanent colour disc type of comparators.

Sometimes interfering substances affect the orthotolodine test. In that case, the starch iodine test can be performed or an amperometric titrator can be used. All of these tests are outlined in "Standard Methods For The Examination of Water and Waste Water".

pH (HYDROGEN ION CONCENTRATION)

The pH is a measure of the hydrogen-ion concentration of a liquid. The higher the concentration, the lower the pH. It will vary from 1.0 to 14.0 with 7.0 being the pH of a neutral solution. Values greater than 7.0 are found in alkaline solutions and those less than 7.0 are found in acid solutions.

This test is important because it is an aid in controlling the operation of sewage treatment plants, although it has no sanitary significance and has little bearing on the strength of sewage. It is of most value in determining the condition of sewage and sludge.

The pH value of raw sewage may give valuable information regarding the presence of trade wastes. Strong alkaline reactions, above pH 8.4 may indicate the presence of excessive quantities of laundry waste or a discharge from some industry employing alkali. Intense acid reactions below pH 6.0 may indicate metal pickling wastes or possibly the discharge of brewery or distillery slop.

Close regulation of the pH value is necessary in the control of biological digestion. Optimum conditions are usually found from pH 6.8 to 7.4. Values much below pH 6.8 indicate acid conditions and in such instances digestion is usually accompanied by foaming and scum formation. Values greater than pH 8.4 may prevent proper growth of biological forms and preclude adequate digestion.

The pH of fresh, raw, domestic sewage normally ranges between 7.0 and 7.6. The pH of septic sewage will be lower.

Testing

(a) The glass electrode method is more accurate than colour comparison. However, the equipment required is more expensive.

(b) The colour comparison method is reasonably accurate. In any case, the relative values obtained by one operator should be quite accurate and with experience the efficiency of operation can be related to different values. The permanent colour discs are preferable to the coloured liquids as there is generally less fading of colours.

The pH of raw sewage should be measured periodically on grab samples to establish the normal range. Tests should then be made whenever an unusual waste is seen or suspected.

The pH of the sludge should be determined about twice each week under normal conditions. More frequent observations should be made if loading rates are changed or unusual conditions develop such as the fall off of gas production.

TEMPERATURE

Temperature readings should be taken frequently enough to establish patterns for various seasons and times in the day. The detection of a sudden drop in the temperature of sewage should

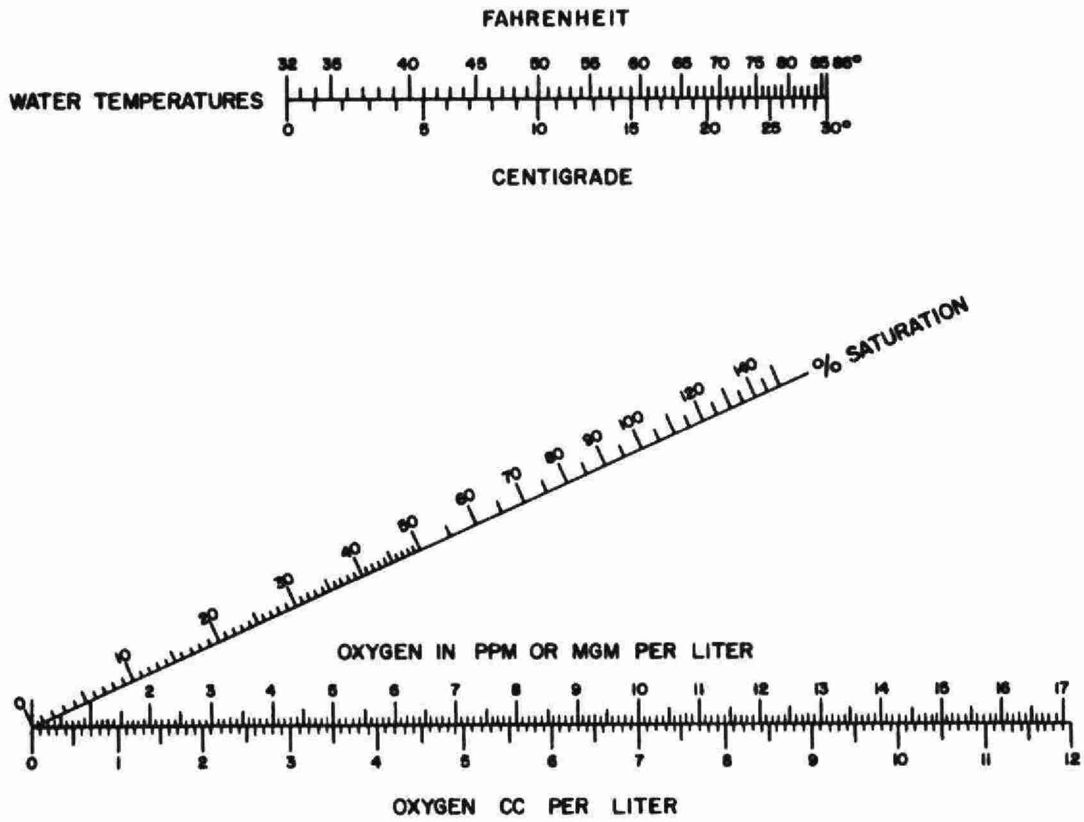
lead the operator to investigate such possible causes as infiltration of cold ground water or surface water. This might enter the system through direct connections or sewer leaks. A significant variation in sewage temperature would be accompanied by a variation in viscocity of the sewage, hence the settling characteristics would be affected. As the temperature of the waste increases, the viscosity decreases and sedimentation is improved. Biological activity, the reason sewage decomposes, is a function of temperature and time. As the temperature increases from 45°F to 105°F the bacterial activity increases. The temperature of sewage is normally a few degrees higher than the water supply of the community.

The only control on temperature in the plant is in heated digesters. These are generally maintained around 90°F. Recording charts are generally installed for recording this temperature.

There are many good quality thermometers on the market. Temperature readings should be taken at least daily.

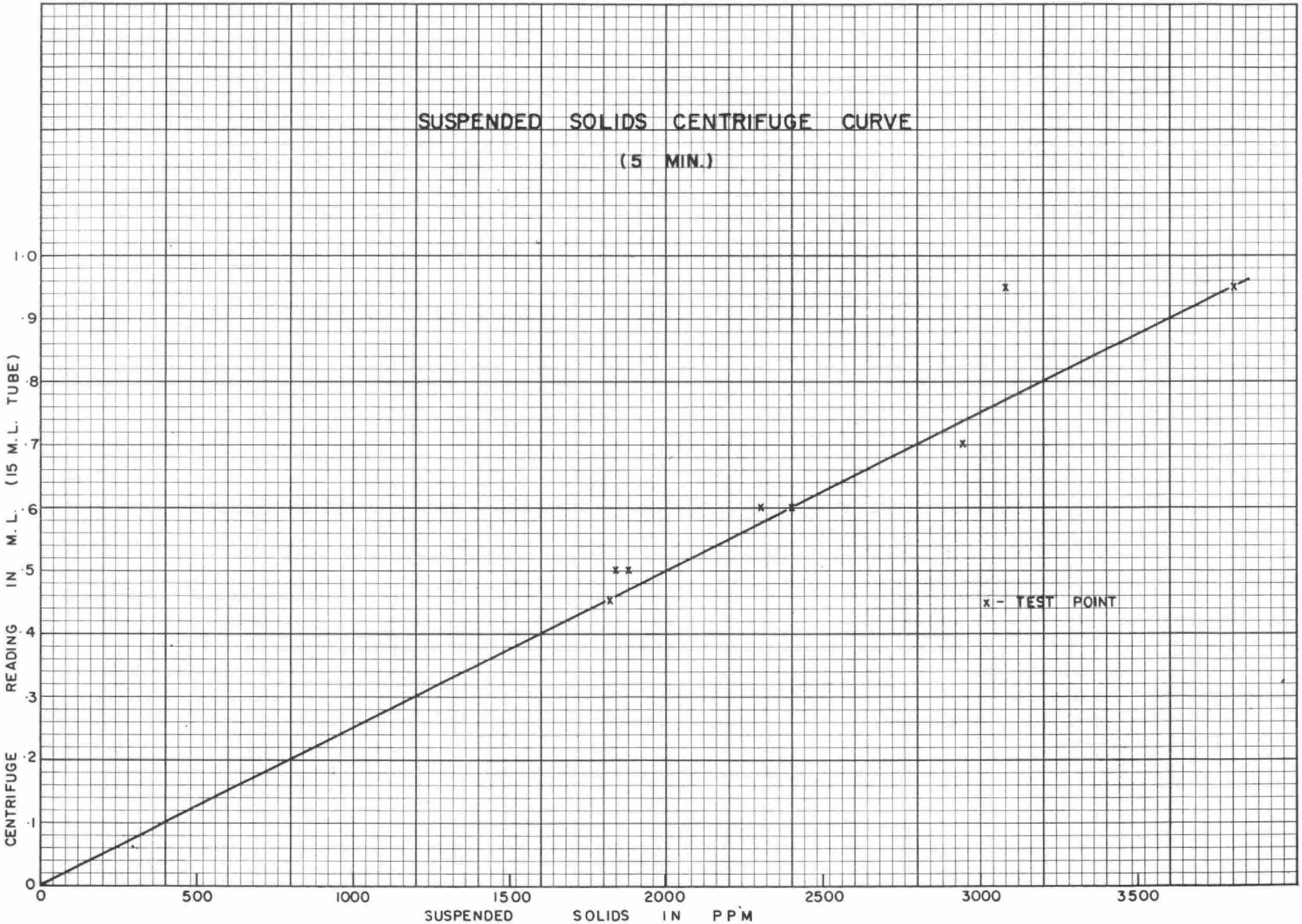
RAWSON'S NOMOGRAM FOR OBTAINING OXYGEN-SATURATION VALUES AT DIFFERENT TEMPERATURES

— FOR NORMAL PRESSURE (760 mm.) AT SEA LEVEL
— FOR NORMAL DISSOLVED SOLIDS (LESS THAN 1000 p.p.m.)



(REDRAWN FROM RAWSON SPEC. PUBL. NO. 15 LIMN. SOC. AM. 1944.)

OWRC. APRIL 1960. J.H.
DWG. NO.: 59 - 18.


SUSPENDED SOLIDS CENTRIFUGE CURVE
(5 MIN.)
CENTRIFUGE READING IN M.L. (15 M.L. TUBE)
SUSPENDED SOLIDS IN PPM
x - TEST POINT
0
·1
·2
·3
·4
·5
·6
·7
·8
·9
1·0
0
500
1000
1500
2000
2500
3000
3500

PRELIMINARY AND PRIMARY TREATMENT

G. H. Mills, P. Eng.

District Engineer
Division of Sanitary Engineering

Preliminary treatment devices are used to protect pumping equipment and reduce some of the load on subsequent treatment units. They are designed to remove or cut-up the large suspended or floating solids, to remove the heavy inorganic solids and to remove excess amounts of greases and oils.

The following units are most commonly used in preliminary treatment:

1. Screens
2. Comminutors
3. Grit channels or chambers
4. Pre-aeration tanks

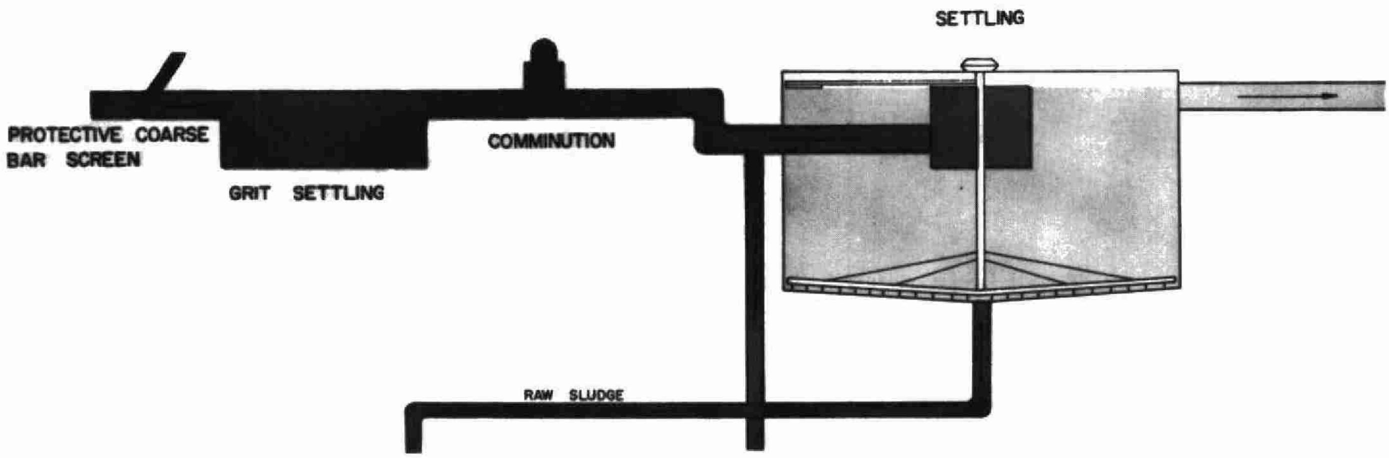
Primary treatment devices are used to separate or remove organic and inorganic settleable solids from the sewage by the physical process of settling or sedimentation. The following types of settling units are the most common:

1. Septic tank
2. Two-storey tank
3. Plain settling tank

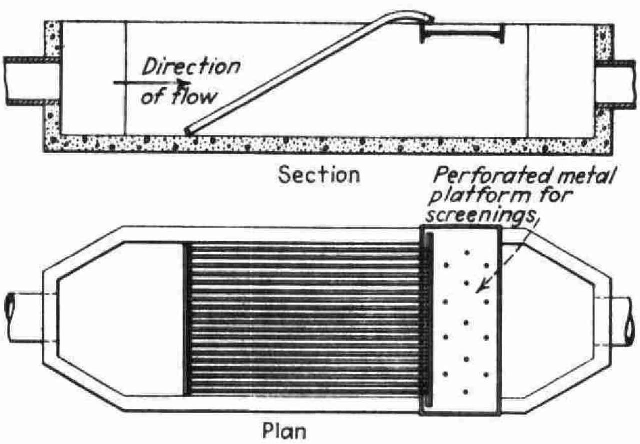
PRELIMINARY TREATMENT

SCREENING

Screens were among the first devices used in attempts to remove potentially harmful solid material from sewage. The most common problem occurs in the form of rags, string, towels, sticks and large pieces of wood and garbage. Without screening, rags may pass through to the digester and wrap around the heating coils, resulting in a loss of heat transfer; blocks of wood can



Preliminary and Primary Treatment Units
FIGURE 1

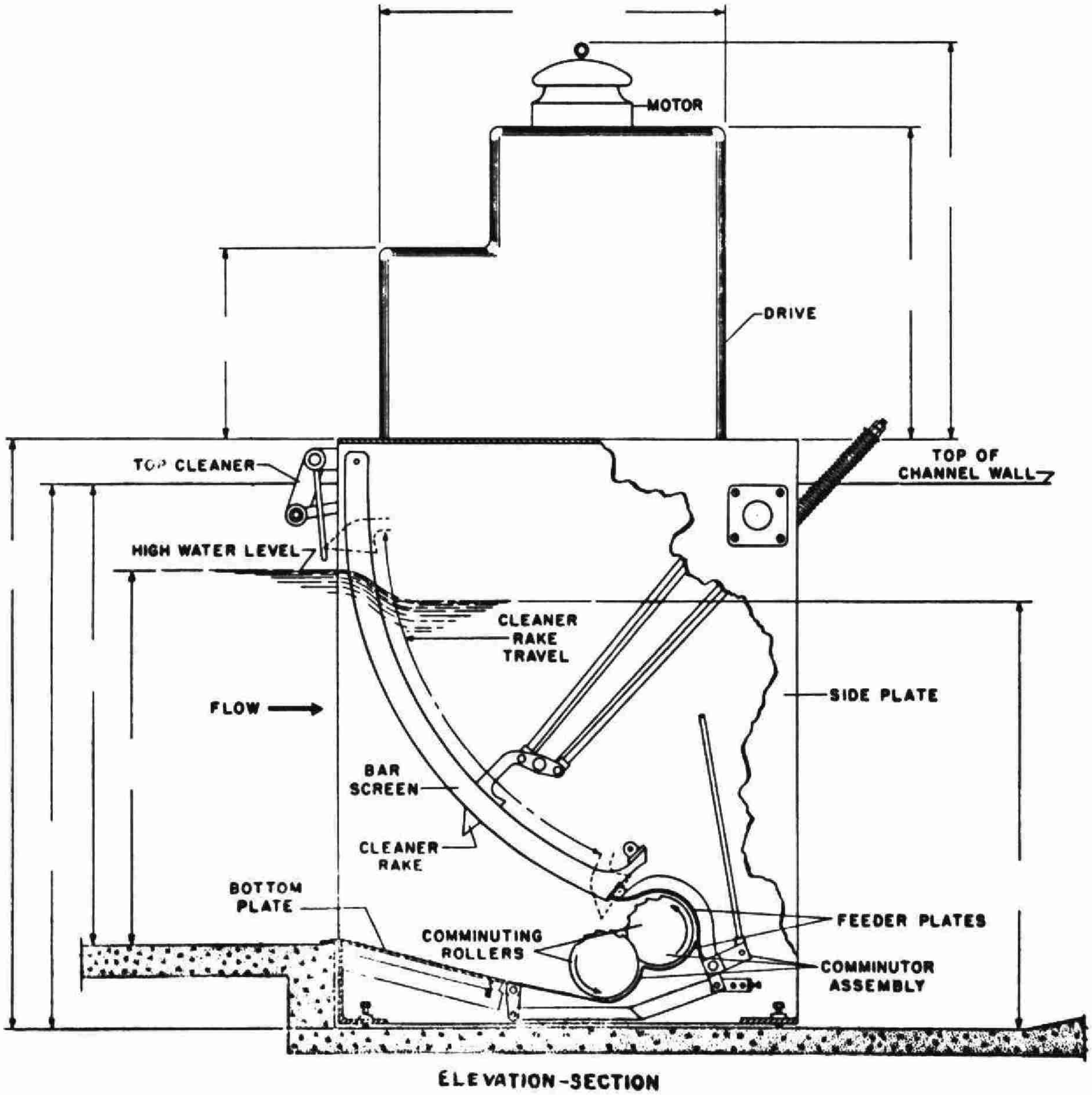


Fixed medium bar rack.

FIGURE 2

The Jeffrey self-cleaning bar rack.

FIGURE 3



Mechanically Cleaned Bar Screen
FIGURE 4

jam the sludge-collection equipment in the primary settling tank; and rags and string may become entangled in impellers of pumps and jam sprockets.

(1) Coarse Screens or Racks

Coarse screens or racks are made of parallel bars with clear openings from 2 1/2 to 6 inches. The rack is usually set at an angle to the sewage flow for easier cleaning. These racks remove only large objects, such as wood, bricks or other flotables which may be washed into a combined sewer system. In such a system, these screens protect pumps and grit chambers which may be installed ahead of the regular bar screens or mechanical shredders.

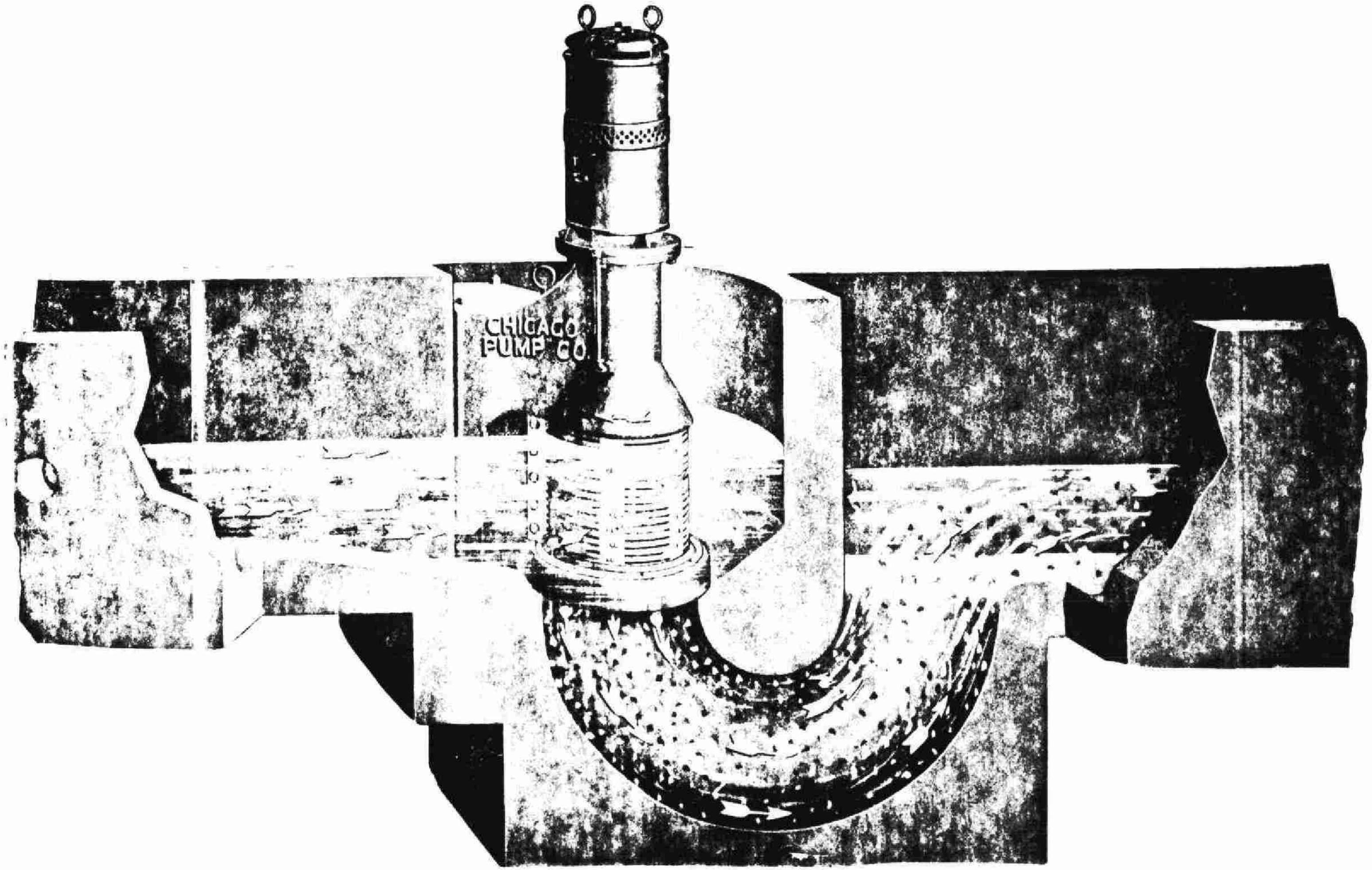
(2) Bar Screens

Bar screens are installed in most plants as either the only unit for screening or as a standby for a comminuting device. See Figure 2. Although these screens are sometimes set vertically, they are normally sloped at 30 to 45 degrees to the vertical and terminate at a platform or basket onto which the screenings may be raked for dewatering. The clear openings between the bar may vary from 3/4 inch to 2 inches, with the most common being in the 1- to 2-inch range.

The velocity of flow through bar screens should be about 2 feet per second to prevent the settling of grit in the screen chamber and to prevent debris from being forced through the screen.

Bar screens may be either manually or mechanically cleaned units. The latter type have rakes (see figures 3 and 4) which periodically sweep the entire screen and they may be front cleaned or back cleaned, the latter not being subject to jamming at the bottom by deposits of trash. Mechanically cleaned devices have certain advantages in that they:

1. reduce labour costs
2. provide better flow conditions
3. produce less nuisance



Comminutor-Showing Cross-Section
FIGURE 5

In some cases these devices are equipped with grinders which return macerated screenings to the sewage.

(3) Fine Screens

Fine screens are mechanically cleaned devices using a medium of perforated plate, woven-wire cloth or very closely spaced bars. The openings are usually 3/16 inch or smaller. Fine screens should be preceded by a coarse screen or a shredder to remove the larger particles.

The band, disc and drum screens are the most common type of fine screens and are used principally in the larger plants where large quantities of screenings are collected. They are all of the moving type, and because of their ability to remove large volumes of material they require constant cleaning. In cases where the waste from a particular industry is causing difficulty, screens of this nature may be used at either the treatment plant or, more commonly, at the industry. Except for special cases they are no longer considered for sewage treatment because of the limited results obtained.

(4) Comminuting Devices

A comminuting device is a mechanically cleaned screen which incorporates a mechanism that cuts the retained material without removing it from the sewage flow. See Figure 5. This tends to reduce odours, flies and unsightliness.

A comminutor is basically a vertically slotted drum screen submerged in the sewage flow. The drum may revolve against cutting members or the cutting members may oscillate against the drum. Travelling cutters are also used in conjunction with a bar screen, the cutters moving up and down on the bars cutting the debris as they move.

Comminuting devices are normally operated continuously, although if possible, the flow should be bypassed through a bar screen for a short period every few days to remove settled material, which tends to dull the cutting edges. Stones, sticks and other unwanted material should be removed from the upstream

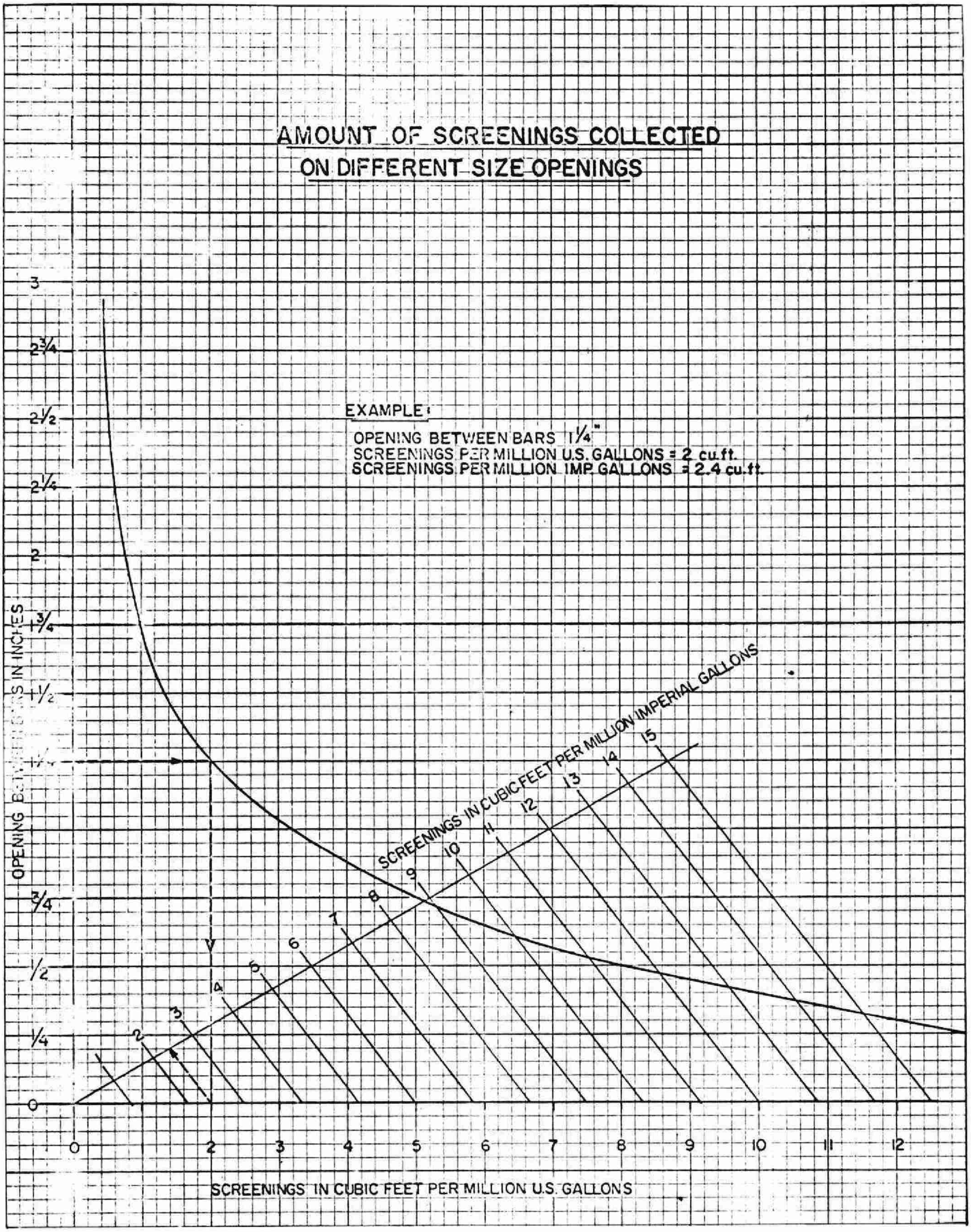

AMOUNT OF SCREENINGS COLLECTED
ON DIFFERENT SIZE OPENINGS
EXAMPLE:
OPENING BETWEEN BARS 1¼"
SCREENINGS PER MILLION U.S. GALLONS = 2 cu.ft.
SCREENINGS PER MILLION IMP. GALLONS = 2.4 cu.ft.
OPENING BETWEEN BARS IN INCHES
SCREENINGS IN CUBIC FEET PER MILLION IMPERIAL GALLONS
SCREENINGS IN CUBIC FEET PER MILLION U.S. GALLONS
0
¼
½
¾
1¼
1½
1¾
2
2¼
2½
2¾
3
2
3
4
5
6
7
8
9
10
11
12
13
14
15

FIGURE 6

side when they are noticed. The unit should be hosed down daily.

Cleaning of Screens

During dry-weather periods coarse trash racks should be cleaned daily and more frequently during storm flows.

Bar screens should be cleaned as often as necessary in order to prevent interference with a reasonably free flow, generally two to five times per day. Failure to clean the screens can result in one or more of the following:

1. Septic action upstream in the sewer
2. Surcharge of sewers
3. Shock loads on treatment units when they are finally cleaned

Screenings

(1) Quantity

A coarse screen - 2 inches or larger openings - will usually collect about 1 cubic foot of solids per million gallons of sewage.

Medium screens - openings ranging from 1/2 to 1 1/2 inches - will ordinarily collect 5 to 15 cubic feet of material per million gallons of sewage. These screenings usually contain considerable organic material and have a moisture content of approximately 80 per cent and weigh 40 to 60 pounds per cubic foot.

Fine screens with openings of 1/16 to 1/8 inch will remove from 10 to 20 percent of the suspended solids.

Figure 6 shows representative volumes of screenings which can be expected from different-size bar screens. However, considerable variations from these figures occur and they cannot be explained by screen openings alone. Other factors affecting the quantity of screenings are the percentage of combined sewers in the system, the character of industrial wastes and the habits of the population served. It has been observed that the sewage

treatment plants serving penal institutions and mental hospitals have much greater than normal quantities of rags in the screenings.

(2) Disposal

The disposal of screenings is a matter that should receive serious consideration since, even if they are thoroughly washed, they may become extremely obnoxious. Methods commonly employed include incineration, burial, drying with raw sludge and maceration and return to flow. The method used will generally depend on the type, size and location of the treatment plant.

Burial of screenings is the practice at most plants. The screenings should be buried in trenches and immediately covered with a layer of earth or washed grit. If the screenings are allowed to remain on drying platforms or in drying baskets for removal only one or two times a day, offensive odours can be prevented by sprinkling them liberally with powdered lime. The screenings should be buried sufficiently deep to avoid odours and flies and shallow enough to permit bacterial activity. A cover of 12 to 18 inches will probably give the best results.

At larger plants, the quantity of screenings is too large for burial at the plant site and the practice is to dispose of them at the municipal landfill site. If the screenings are to be removed from the plant for disposal, they should be deposited in covered cans either immediately after they are removed from the screens or after allowing a short period of dewatering. In the warmer months, to keep fly and odour problems to a minimum, the screenings should be washed down by hosing them on the drying platform.

Grinders are widely used for the disposal of screenings. The material is reduced in size and returned to the raw-sewage flow or mixed with sludge depending on the location of the grinders in relation to other treatment processes.

Material from the grinder either settles out in the primary settling tanks or are mixed directly with the raw sludge. The screenings become part of the raw sludge or primary scum introduced to the digester and are decomposed by the same action as the other solids. It is desirable, therefore, that the screenings be ground as fine as possible. Some digester foaming or excessive

scum blanket formation has been attributed to this method of disposal of screenings but proper scum control can overcome this problem.

Incineration of screenings has been found to be moderately satisfactory at some plants in the U.S. However, this method is not used in Ontario at present and most of the U.S. plants have abandoned it, except at the largest plants.

GRIT REMOVAL

At one time it was believed that a separate sewer system did not warrant the need for grit-removal facilities. However, a considerable quantity of grit-type material is present in sewage because of industrial and domestic discharges and faulty sewer joints. Some grit enters through street drains, combined sewers or foundation drains. Where joints are poorly constructed, and the ground-water level is above the pipe, coarse sand may be admitted in substantial amounts.

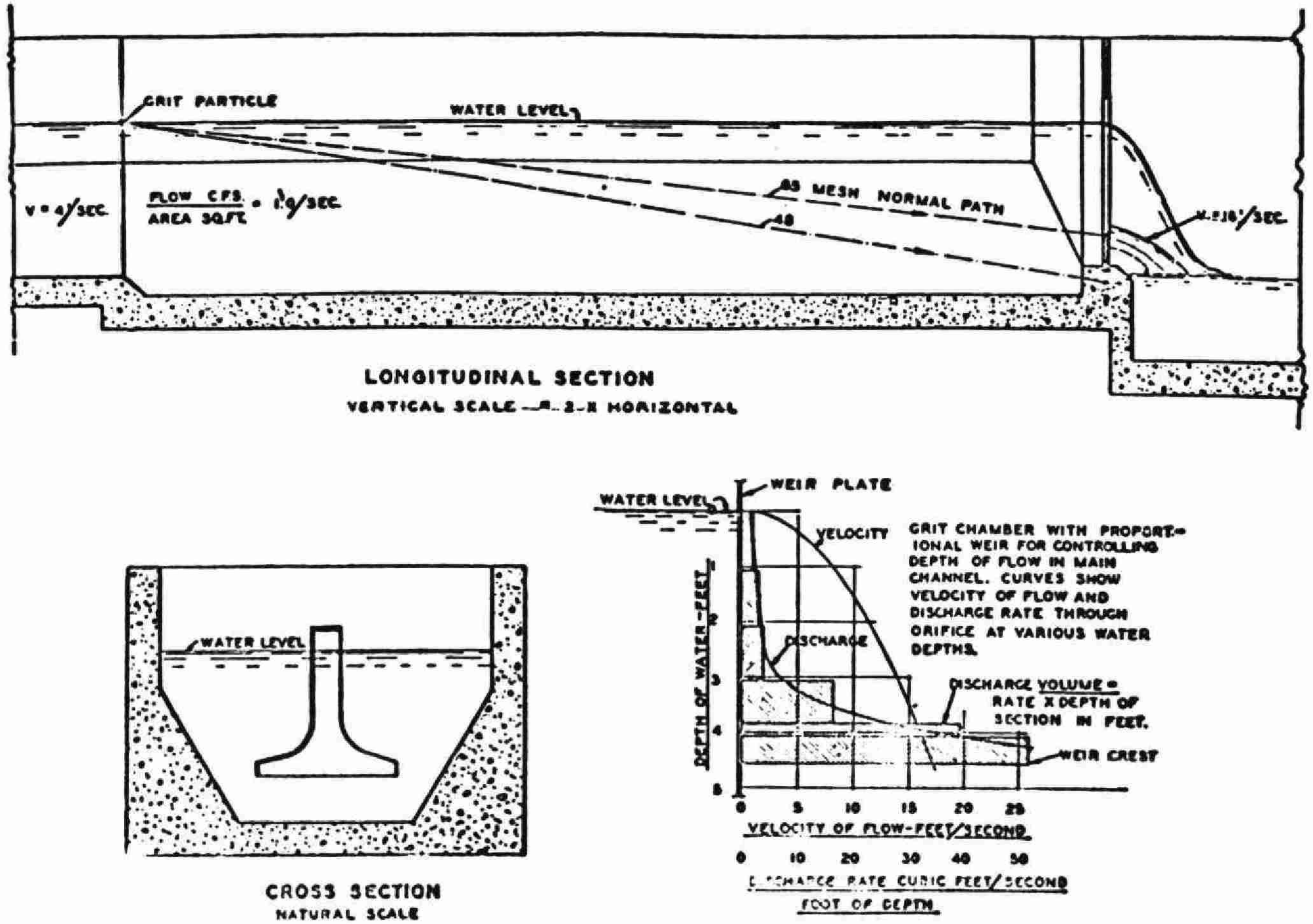
Grit removal prevents abrasive action on pump impellers and collector mechanisms, reduces clogging of pipes, tanks and hoppers, and eases sludge handling and disposal.

There are many types of grit removal units, but in reality there are basically two - manually cleaned and mechanically cleaned units. Manually cleaned units are used in smaller plants. Mechanical units are used where there are relatively high flows, large quantities of grit or the depth of the unit is too great for manual removal.

Types of Units

There are three major categories into which removal facilities may be placed. There are:

(1) grit channels
(2) aerated grit chambers
(3) mechanical devices



Rectangular Grit Channel
FIGURE 7

(1) Grit Channel

The rectangular grit channel equipped with a proportional weir at the outlet end is the most common type of grit removal unit. Figure 7 shows this unit. The chamber is slightly larger in cross-section than the inlet sewer.

By reducing the flow from the usual 2 feet per second in the inlet sewer to 1 foot per second in the channel, the heavier, inorganic solids will be deposited, while the lighter organic solids will remain in suspension. The rate of flow is maintained at a more or less constant velocity by

(1) gates
(2) proportional weirs
(3) flumes

The normal cleaning operation for manually cleaned units is as follows:

1. When grit accumulates to one-half of the liquid depth in the first half of the grit channel length, switch to clean channel.

2. Dewater channel (if this is possible without washing out grit)

3. Remove grit after it is well dewatered

4. Measure and record quantity

5. Flush channel clean

6. Bury grit

It is not essential to remove water but if it is possible it lessens the work. If there is only one channel the problem is increased because of stirring and flushing to other parts of the plant. Generally, clean these at the lowest flow possible. A low velocity of flow is equally important at this time; therefore, close outlet end and increase depth.

In plants where only one mechanically cleaned channel is

provided, a manually cleaned unit may be employed as a bypass. Automatic or semi-automatic collectors are usually conventional conveyor-type equipment with buckets, plows, scrapers or rakes. A grit-washing or classification device may be included.

When mechanically cleaned grit chambers are in use, they should be cleaned at regular intervals to prevent undue loads on the cleaning mechanisms. Time-clock operation may be provided. It is difficult to say how often they should be operated, but continual operation is extremely rare.

(2) <u>Aerated Grit Chamber</u>

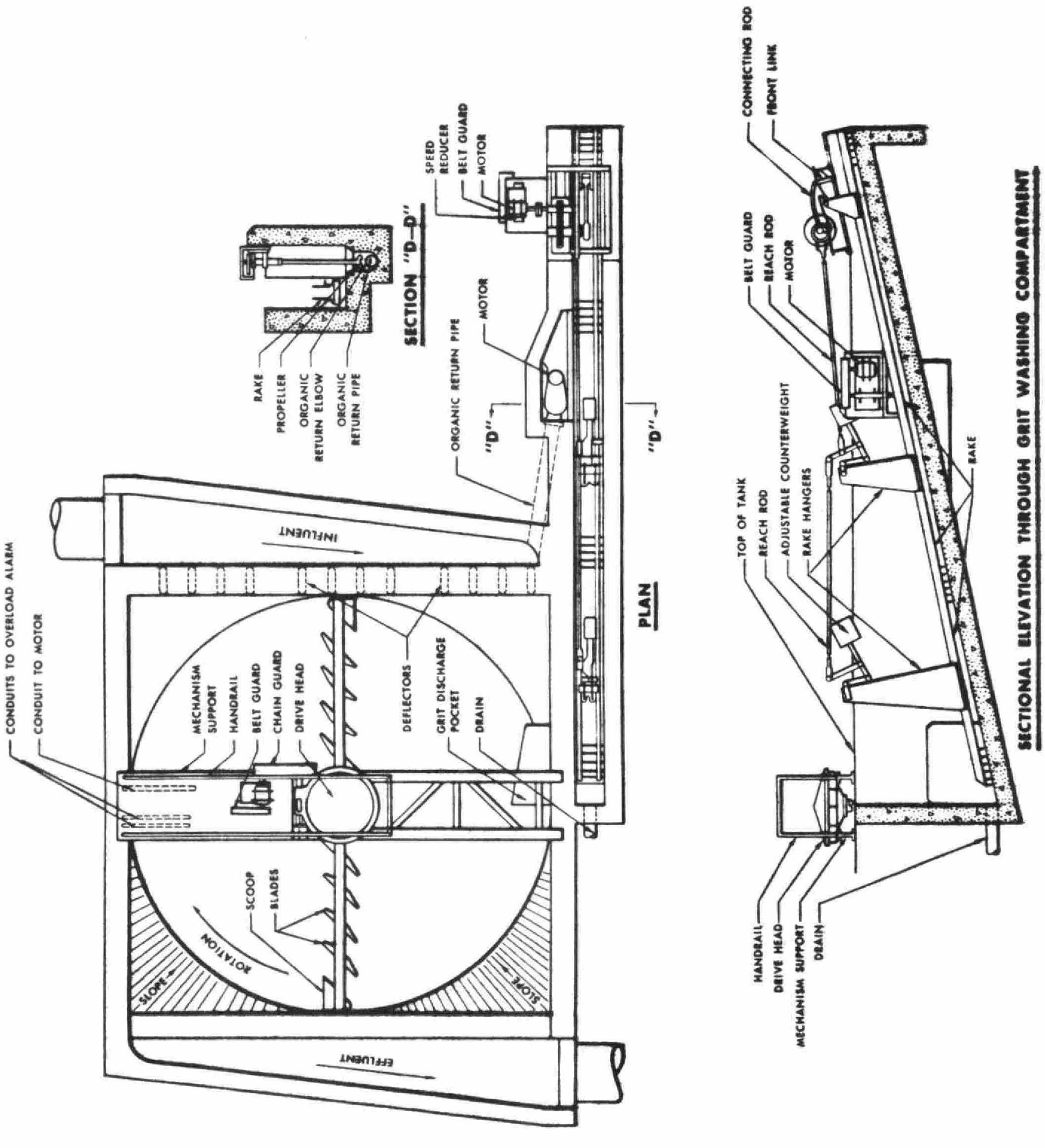
Grit can be made to settle in a spiral flow aeration tank and will accumulate beneath elevated air diffusers mounted along one of the longitudinal walls of the tank. The diffusers are mounted approximately 2 feet above the bottom. Hoppers are provided beneath the diffusers for collecting the grit. Flow enters the tank at the opposite end of the effluent weir and in a direction to coincide with the roll of tank contents. The heavier particles will settle to the bottom while the lighter, organic particles are carried with the roll and eventually discharged from the tank.

Flow velocities of 2 feet per second are developed in aeration tanks with air supplied at the rate of 3 cubic feet per minute per foot of tank length.

Removal of the accumulated grit from the hopper may be done by:

1. Clamshell bucket
2. Air-lift (if lift is not greater than 5 to 10 feet above liquid surface)
3. Jet pumps

One disadvantage to aerated grit removal is that it produces a clean grit. As grit yield goes this may be all right, but many operators also want to remove much of the cellulose and hair-like particles which, if not taken out with the grit, add to the digester inert scum layer. A detention tank is preferred in these cases.



Dorr Detritor
FIGURE 8

(3) Detritus Tank

Short-period sedimentation in a tank that operates at substantially constant levels produces a mixture of grit and organic solids called detritus. The lighter organic solids are subsequently removed from or washed out of the mixture.

Several manufacturers specializing in sewage disposal equipment have perfected this type of equipment. The Dorr Company has developed one such unit called the "Detritor" and this device is shown in Figure 8. It is noted that the detritor not only removes the grit but also washes it. A later section of this paper will deal with washing or classification devices.

The grit-collecting mechanism is installed in a square, shallow, concrete tank with filled-in sloping corners. Sewage enters along one side of the tank through adjustable vertical gates, which are set to provide a uniform influent velocity across the entire width of the unit. After entering, the sewage flows in straight lines across the tank and overflows at a weir constructed along the outlet side of the tank.

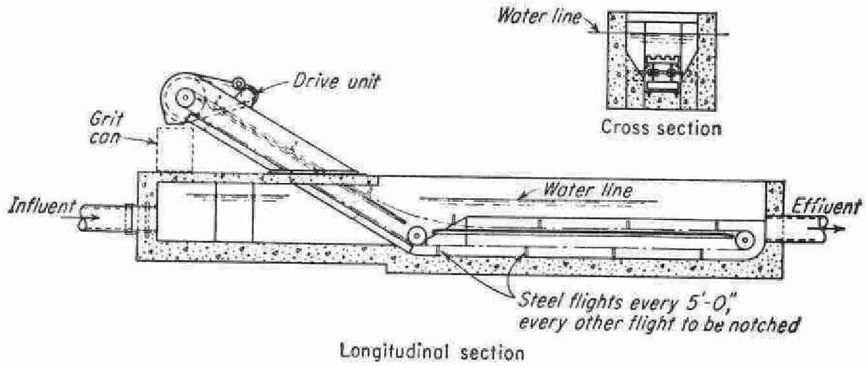
The collecting mechanism consists of two structural-steel arms, attached to a vertical shaft and fitted with outward raking blades with scoops on the ends. As the rakes revolve, settled grit is plowed outward to the radius where the end scoops collect and discharge it to a hopper at one side of the tank.

The grit is then discharged to a washing or classifying device.

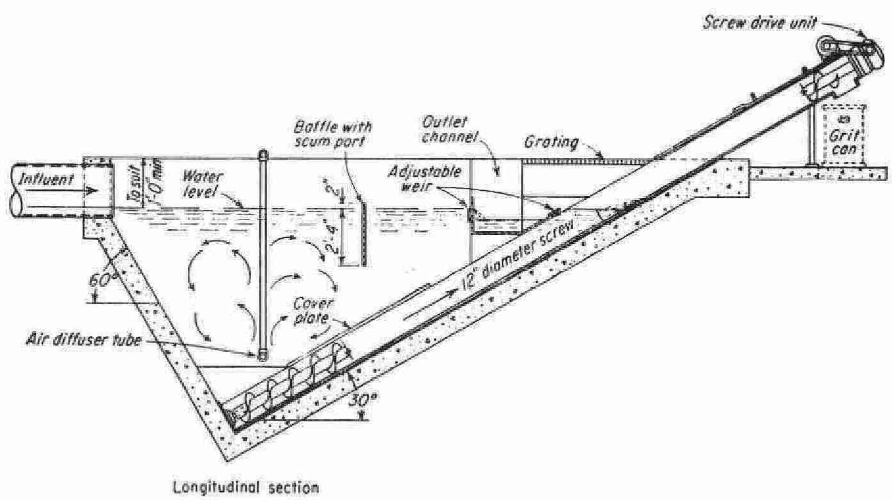
Cleaning Grit

In order to obtain a relatively clean grit (less than 3% volatile matter) various methods of washing out the excess organic materials have been developed.

1. Elevation on a sloping ramp by means of a series of reciprocating rakes (refer to Figure 9). The reciprocating rakes convey the grit up the inclined tank and at the same time impart a rolling action which releases the entrained organic matter. The organics are pumped back to the inluent end of the tank by a



Mechanically Cleaned Grit Chamber
(Jeffrey Manufacturing Co.)
FIGURE 9



Aerated Grit Chamber with Screw Conveyor
(Link-Belt Co.)
FIGURE 10

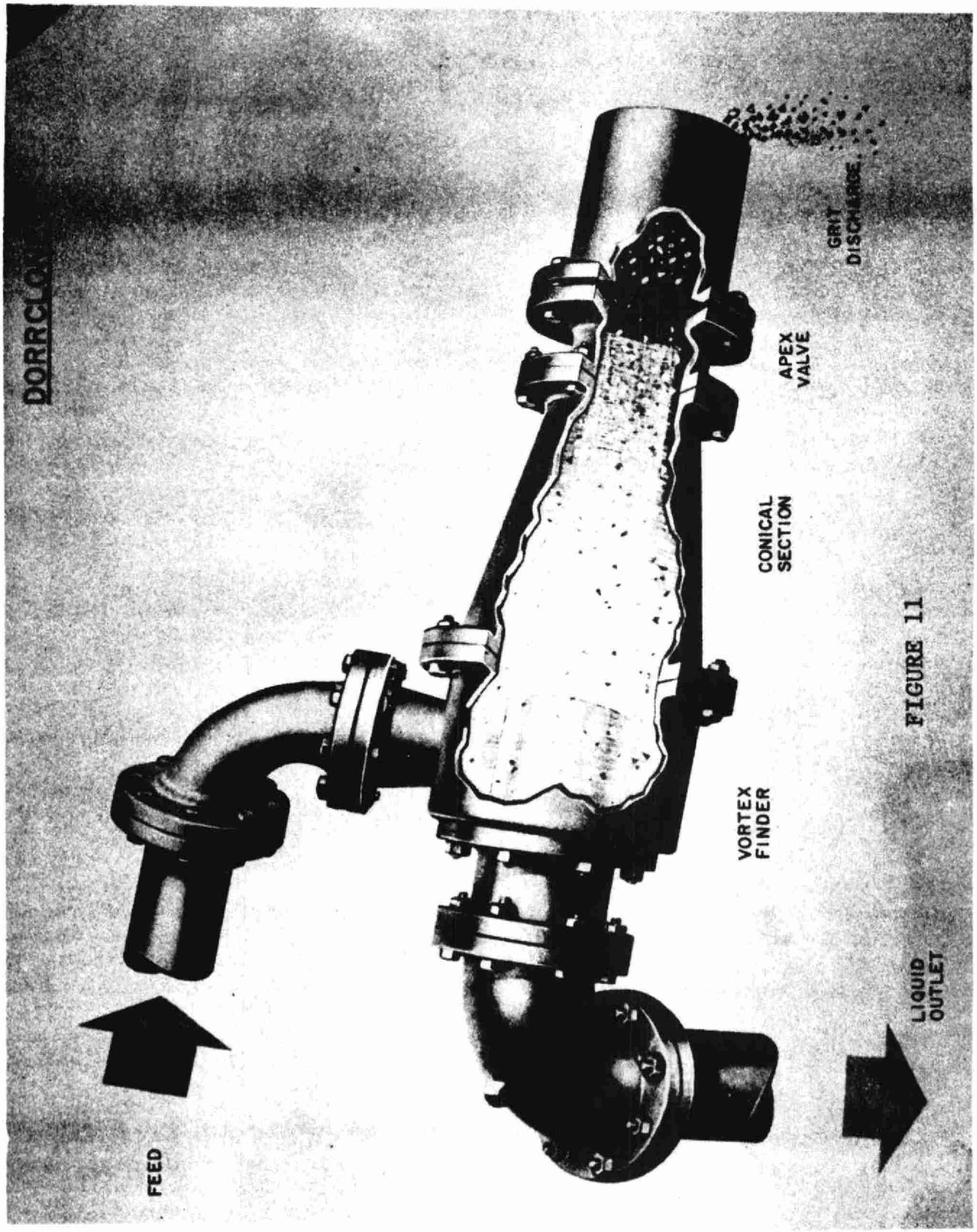

DORRCLON
FEED
VORTEX FINDER
CONICAL SECTION
APEX VALVE
GRIT DISCHARGE
LIQUID OUTLET

FIGURE 11

pump which acts similarly to a propeller in a draft tube. Excess moisture drains off as the grit progresses up the latter part of the ramp.

2. Elevation by screw conveyor in a sloping trough. The action of this type of grit washer is basically the same as that described for the reciprocating-rake process. See Figure 10.

3. Aerated grit chambers -- the use of diffused air for grit removal as previously described produces a well "washed" or classified grit.

4. "Cyclone" classification units -- a diagram of one type (Dorr) of these units is shown in Figure 11. The slurry enters the cylindrical feed chamber tangentially and develops a cyclonic vortex pattern. Centrifugal forces throw the grit contained in the slurry to the walls of the cone. As these solids collect along the walls of the cone, they move towards the apex and discharge through the apex valve. The lighter, grit-free liquid moves to the inner spiral of the vortex where it is displaced into the overflow opening (vortex finder). Usually the flow from this type of unit is wetter than that of the reciprocating rake type unit; however, they remove grit up to a 150 mesh.

Under certain circumstances these units are used for the removal of grit from raw sewage.

Quantity of Grit

As in the case of screenings, it is not possible to state how much grit can be expected at each plant. Many variables affect the volume of grit. Average figures for the expected quantities of grit are 8 cubic feet per million gallons for combined-sewer systems and 3.5 cubic feet per million gallons for separate-sewer systems.

Disposal of Grit

Clean grit is characterized by the lack of odours which would normally result from the presence of decomposing organic matter. Except when grit is carefully washed, it will contain

up to 50 percent organic matter (mostly garbage) by weight. It is inevitable that some food value will be found in such grit and consequently it will become an attraction to insects and rodents as well as unsightly and odorous.

In the majority of cases, grit is disposed of by burial or at the municipal dump or landfill site. At the plant, unwashed grit which is removed from the removal facility should be kept in cans and should be removed to the disposal site at least daily. If the grit is adequately washed (less than 3% volatile) it may be used as fill around the plant or it may be used to re-sand sludge drying beds.

Laboratory Control

The volume of grit removed should be recorded each time hand cleaned units are emptied. Daily records should be kept for mechanically operated units.

The percent volatile matter should be determined regularly where laboratory facilities are available. Tests should be made daily for mechanically cleaned units and for each batch removed in hand cleaned units.

Where laboratory facilities are not available at the plant, periodic samples may be submitted to the OWRC laboratory of the sewage entering and leaving the grit removal chamber. Volatile solids content of these samples will indicate to some extent the percent efficiency of the unit.

The grit may be nearly all organic or all inorganic.

No analysis gives a positive evaluation of the efficiency but if one test is done regularly changes will be indicated.

Pre-Aeration

Aeration basins preceding or following screens and grit chambers aerate the raw sewage for one of more of the following purposes:

1. To remove gases from the sewage, especially hydrogen sulphide, which create odour problems, and also increase the chlorine demand of sewage. The release of gases and the addition of oxygen reduce odours in septic sewage. For effective results an aeration period of 30 minutes to several hours may be required.

2. To promote flotation of excessive grease, which then can be removed from the raw sewage at an early stage in its treatment.

3. To aid in the coagulation of the colloids (finely divided suspended solids) in the raw sewage for the purpose of obtaining a higher removal of suspended solids by primary settling.

4. Treatment of digester supernatant.

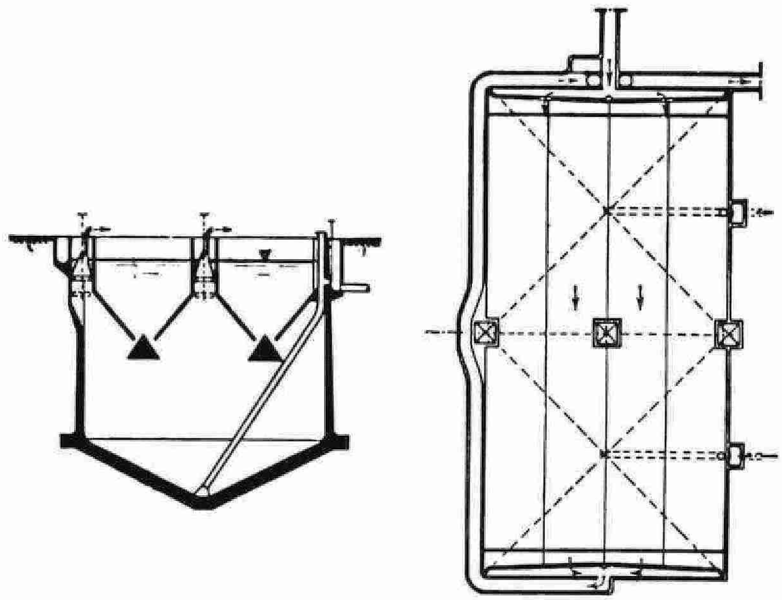
In general, pre-aeration tanks are designed for detentions of 5 to 15 minutes for grease removal, using 0.01 to 0.1 cubic foot of air per gallon of sewage treated. If flocculation of the fine suspended solids in the raw sewage is also attempted, the detention period must usually be extended to at least 15 to 60 minutes, the average time being about 30 minutes.

Aeration increases the skimmings or grease produced since the rising air bubbles attach themselves to heavier-than-water particles causing buoyancy. This buoyancy holds the grease particles in the surface flow. Some de-emulsifying of the grease also occurs which separates it from the sewage. The skimmings are removed several times a day by hand (at least twice) or by various makes of skimming devices, or they may be permitted to discharge to the primary settling tanks for removal.

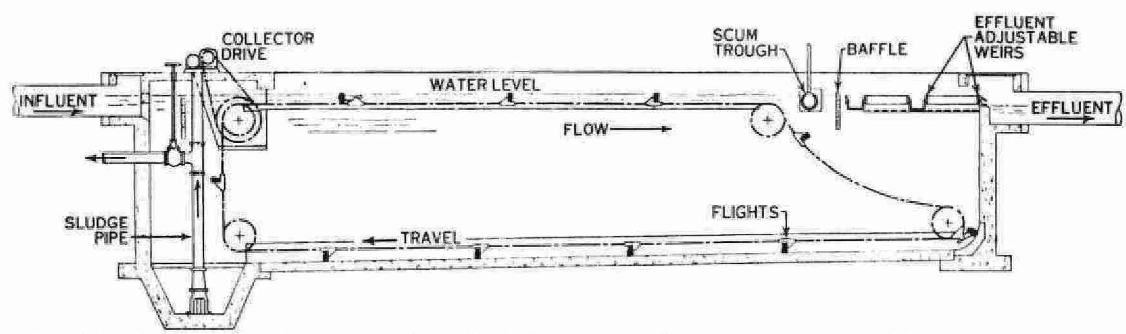
The sides of the basin should be hosed down daily and the skimming device should be hosed after each use.

PRIMARY TREATMENT

Primary sedimentation devices are designed to remove organic and inorganic settleable solids, by the physical process of settling. This is done by reducing the velocity of flow. In preliminary treatment this velocity is lowered from a velocity of 2 fps in the inlet sewer to about 1 foot per second for a very



Imhoff Tank
FIGURE 12



Longitudinal section of a primary rectangular tank with Straightline sludge collector. Upper run of flights pushes scum to scum trough. Skimming is not provided in final tanks. Multiple effluent weirs provide a low overflow rate.

Rectangular Plain Settling Tank
(Link-Belt Straightline)
FIGURE 13

brief period during which the heavier inorganic solids are settled out as grit. In primary treatment the velocity of flow is reduced to a fraction of an inch per second in a settling or sedimentation tank for a sufficient length of time to allow the major portion of the settleable solids, which are largely organic, to settle out of the sewage flow. The effluent contains all dissolved organic wastes and the remaining suspended solids which are impractical to settle out.

There are a number of types of primary treatment devices or sedimentation tanks which are available and are in use.

Septic Tanks

Septic tanks are designed to hold the sewage at a very low velocity under anaerobic conditions for a period of 12 to 24 hours, during which time a high removal of settleable solids is effected. Septic tanks are no longer used except for very small installations such as residences and schools.

The length is usually 2 to 3 times the width in order to prevent short-circuiting and the accumulated sludge is removed two to three times per year by pumping or by ports in the bottom of the tank.

Two-Storey Tanks (Imhoff Tank)

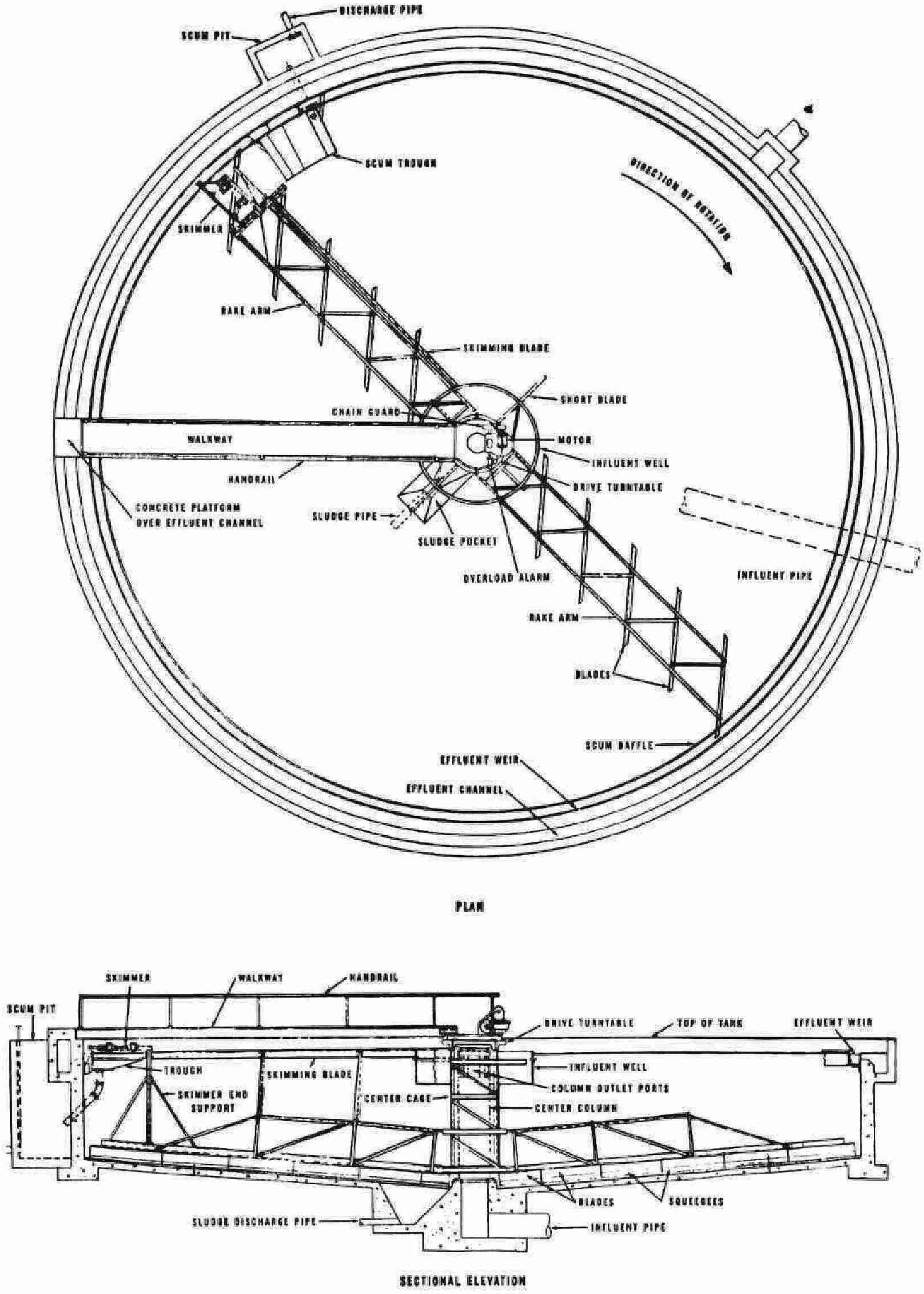
These units are no longer built because they are expensive to construct due to different framework and excessive depths (30 ft. +). Retention periods vary from 1 1/2 to 4 hours, depending on the type of additional treatment. See Figure 12.

The following should be considered with respect to operation.

(a) Daily removal of grease, scum, and floating solids from the sedimentation compartment.

(b) Weekly scraping of sides and sloping bottom.

(c) Monthly reversal of flow (if possible).



Circular Plain Settling Tank
(Dorr Type S-7)
FIGURE 14

(d) Control of scum in scum chamber - break and if depth exceeds 2 feet it should be removed.

(e) Removal of sludge before depth approaches 18 inches of slot.

Plain Settling Tanks - Mechanically Cleaned

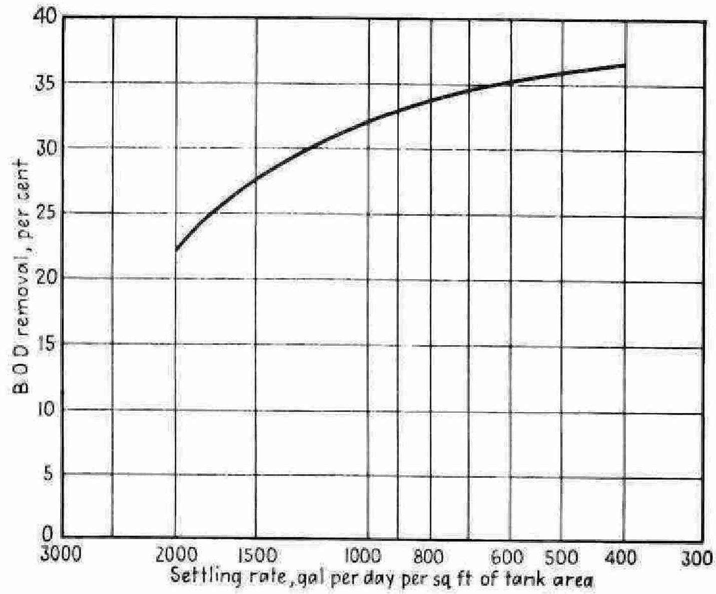
These tanks may be rectangular, circular or square, but all operate on the same principle of collecting the settled solids by slow-moving scrapers to a point of removal. See Figure 13.

The settled solids are taken from the tank continuously or at frequent intervals so that decomposition with gas formation does not have time to develop. The solids are then handled by other units which will be discussed in other lectures in the series.

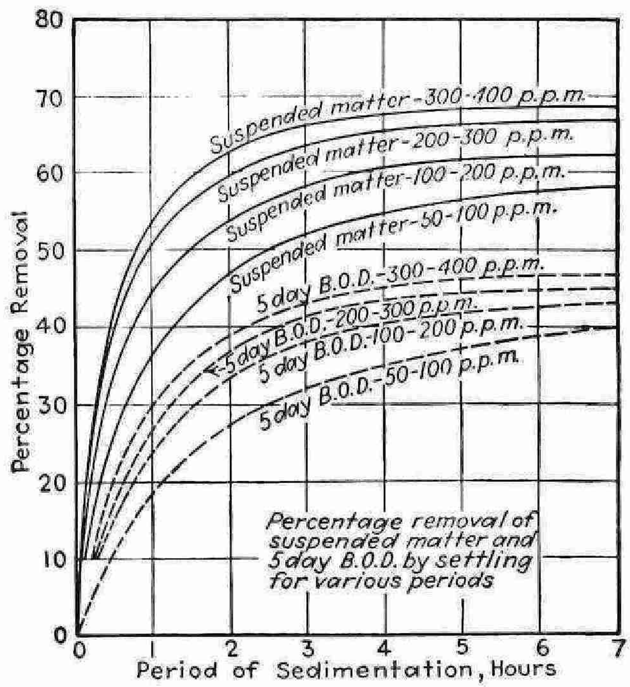
In the rectangular tanks the scrapers are attached near their ends to two endless chains with pass-over motor-driven sprockets. The scrapers are dragged slowly along the tank floor pushing the settling solids to the sludge hopper located at the inlet end of the tank. The scrapers are then lifted by the chains to the surface of the tank they serve to push floating solids, grease and oil to a scum collector at the outlet end of the tank. Another type of mechanism consists of a travelling bridge spanning the tank from which is suspended a blade to push solids to the point of removal and a skimmer blade for floating solids, grease and oil. These blades operate when travelling in one direction and idle when travelling in the return direction.

The circular sedimentation tanks have scraper arms attached to a central motor driven shaft. The bottom of the tanks are sloped towards the centre and the scrapers move the settled solids to a sludge hopper at the centre. Skimmer arms are attached to the central shaft at the surface for collection of floating solids, greases and oils. See Figure 14.

In the square tanks the mechanism is similar to that in the circular tanks. The major difference is that one or both of the rigid arms of the mechanism are equipped with pivoted corner blades which reach out into the four corners of the tank



Overflow Rates and BOD Removal
FIGURE 15



Period of Sedimentation and BOD
and Suspended Solids Removal
FIGURE 16

and remove the solids in these areas to the path of the circular mechanism.

Design of Plain Settling Tanks

Inlets

Inlets should be designed to dissipate the inlet velocity, diffuse the flow equally across the entire cross section of the tank and prevent short-circuiting. They may be of the weir type but are commonly a channel with spaced port openings.

Baffles

These are placed at the inlet, to diffuse flow, and at the outlet ends of the tank, to hold back floating solids. Mechanically cleaned tanks usually have a scum trough, which serves as the outlet baffle.

Outlet Weirs

Outlet weirs are designed to remove the settled sewage as a thin sheet from the surface of the tank. They are usually adjustable. It is important that they be kept level. The term "weir loading" is used to express the gallons per day passing over 1 foot of the weir. In plants less than 1 mgd capacity this should not exceed 10,000 gallons per linear foot per day but may be up to 15,000 for larger plants.

Surface Settling Rate

This is expressed in terms of gallons per square foot of tank area based on the daily sewage flow. The rate should not exceed 600 gallons per square foot per day for plants less than 1 mgd but may be in the range of 900 to 1,200 for larger plants. This rate is an important factor and is directly related to the percent removal of BOD and suspended solids. See Figure 15.

Detention Period

This is simply the length of time the sewage is held in the tank based on the sewage flow and tank volume, assuming uniform flow and total displacement. It was once used as the sole basis for tank design but has since been replaced by weir loading and surface settling rate. The detention period should be at least 2 hours. See Figure 16.

Efficiency

About 40 to 60 percent of the total suspended solids can be expected is plain settling tanks. The BOD should be reduced by about 25 to 35 percent. Such figures are general and cannot, of course, be applied to specific cases. The efficiencies of removal for various sewage strengths are shown on Figure 16.

Operation of Mechanically Cleaned Tanks

The establishment and maintenance of proper time schedules for operation of the mechanical cleaning equipment and for the removal of sludge from the tank are the most important factors in tank operation. They must be determined for each plant.

In general, circular-tank sludge collecting mechanisms are operated over longer periods than rectangular-tank collectors. Mechanical sludge collectors in the circular tanks are often run continuously, whereas with rectangular tanks the collectors may only be operated from 3 to 12 hours per day. They should be run often enough to prevent a build-up of solids on the tank bottom. If the solids are allowed to build up in the tank, an undue load may be placed on the mechanism at start-up and cause damage to the equipment. Also, the tank volume is reduced resulting in a lower retention period. Solids may also be decomposed with the resultant production of gas in the settling tank and some floating sludge. Before sludge is removed from the tank the mechanism should be run for a sufficient time to assure satisfactory collection of bottom solids in a sludge hopper.

General operations should include daily cleaning of all vertical and inclined walls and the removal of all material from

baffles.

Frequent determinations of the sludge level should be carried out to ensure removal prior to decomposition. Gas bubbles and floating sludge are definite indications of decomposition.

Sludge Withdrawal

The air in raw sludge withdrawal is to secure as dense a sludge as possible, preferably in the range of 5 to 7 percent total solids, and to clear the settling tank hoppers as thoroughly as possible without drawing liquid. Sludge may be removed by hydrostatic pressure in smaller installations or by pumping. The manner in which sludge is removed has a great effect on both the settling tank and the digester.

Raw Sludge Sampling

Raw sludge volumes often vary considerably from day to day. Consequently, to control pumping periods properly, at least one good method of raw sludge sampling is needed at every plant. Any of the following may be employed:

1. Visible outlets, including discharge pipes above the maximum liquid level to raw sludge concentration tanks, or to a control box adjacent to the roof of the sludge digestion tank, have been installed.

2. A sight glass provided by one manufacturer can be inserted in the discharge pipe from the sludge pumps.

3. A sampling tap located either near the raw sludge pumps or in a sludge digestion tank gallery is frequently provided.

4. Many operators use a sampling device on the discharge side of the sludge pumps for observation of the pumped sludge. This method is advantageous where long sludge discharge lines are used.

As a general guide, if a sample of sludge in a test jar

after settling for 10 minutes shows more than 50 percent volume of sludge, pumping should be continued. If it shows less than 50 percent, removal may be considered reasonably complete.

It is generally better to remove sludge three to four times a day and provide a more constant food supply to the organisms doing the work rather than to remove all of the daily sludge accumulated at one time. If too little sludge is removed the clarifier effluent will deteriorate. If too much is removed the digester operation will deteriorate and extra supernatant must be treated.

Scum Removal

Removal of scum,floating garbage, and grease is universally recognized for efficient operation of settling tanks. A scum barrier or baffle is generally provided somewhere in the flow path, between the centre of the tank and the effluent weir. Excessive skimming will result in too much water being carried out with the scum, while insufficient skimming will permit scum to flow around or under the baffle and from the tank effluent. Scum must be removed daily and ideally small amounts should be removed continuously.

Chemical Precipitation

This is a modified sedimentation process where a coagulant is employed to improve the efficiency of settling. Chemicals used are alum, ferric chloride, lime, etc. Proper mizing is essential and the dosages will vary with the sewage. The process is not popular due to cost and volume of sludge produced. Efficiencies of 80-90% removal of suspended solids and 50-55% removal of BOD are common.

SAFETY PRACTICES IN SEWAGE WORKS

R. J. Norton

Safety and Training Officer

INTRODUCTION

The dangers associated with sewage works operation emphasize the need for safety practices. Physical injuries and body infections are a continuous threat and occur with regularity. Explosions and asphyxiations from gases or oxygen deficiency occur at sewage plants and during sewer maintenance and although infrequent at any particular location, on a country-wide basis many such accidents occur. These occupational hazards may be largely avoided by the execution of safe practices and the use of safety equipment. The dangers are many and carelessness all too frequently prevails until an accident results. Then it is too late.

It is the responsiblity of sewage works supervisors to acquaint themselves with the hazards associated with plant maintenance and operation and to take steps to avoid them. Accident prevention is the result of thoughtfulness and the application of a few basic principles and knowledge of the hazards involved. It has been said that the "A, B, C" of accident prevention is "always be careful". However, one must learn how to be careful and what to avoid. With this knowledge one can then always think and practice safety.

HAZARDS

The overall dangers of accidents are much the same whether in manholes, pumping stations or treatment plants. These hazards may be as follows:

1. Body infections
2. Physical injuries
3. Dangers from noxious gases or vapours and oxygen deficiencies.

NO. 1 Body Infections

This hazard to plant personnel although very real and ever present can be largely reduced by the operator himself by following a few basic rules of personal hygiene. A few of these self applied rules are as follows:

1. Never eat your lunch or put anything into your mouth without first washing your hands.

2. Refrain from smoking while working in open tanks, on pumps, or cleaning out grit channels etc. Remember you inhale or ingest the filth that collects on the cigarette from dirty hands. Save your smoking time for lunch hours or at home.

3. A good policy is "never put your hands above your collar when working on plant equipment".

4. Always wear your rubber boots when working in tanks, washing down etc., don't wear your street shoes.

5. Don't wear your rubber boots or coveralls in your car or at home.

6. Always wear rubber or plastic coated gloves when cleaning out pumps, handling hoses etc.

7. Don't just wash your hands before going home, wash your face too, there is as much of your face to carry germs as there is of your hands.

8. Wear a hat when working around sludge tanks, cleaning out grit and other channels, don't go home with your head resembling a mop that just wiped up the floor around a cleaned out pump.

9. Keep your finger nails cut short and clean, they are excellent carrying places for dirt and germs.

Workers who come into contact with sewage are exposed to all the hazards of water-borne diseases, including Typhoid Fever, Amorbic Dysentery, Infectious Jaundice and other intestinal infections. Tetanus and skin infections must also be guarded against.

A majority of infections reach the body by way of the mouth, nose, eyes and ears. Therefore, washing your hands is a must before eating or smoking. Wear protection gloves where possible.

Soap preparations requiring no water rinse are available for field use. The common drinking cup should be banned, each man should have and use his own.

Typhoid and Tetanus innoculations are recommended. These may be obtained free of charge from local Health Officers.

Wearing Apparel

Rubber or rubberized cotton gloves, rubber boots and coveralls are designed for body protection against dampness and contact with dirt, wear them at all times when working in tanks etc.

Rubberized or rain suits can be worn in very wet or dirty places and can be washed off with a hose and brush, the same as rubber boots.

Hard hats should be available and worn when working below ground level, i/e in open tanks etc., or in confined areas with low head room or during any construction on the plant site. Always wear safety goggles when grinding, chipping or scrapping and wire brushing old painted surfaces.

PHYSICAL INJURIES - First Aid

Except for minor injuries, wounds should be treated by a doctor and reported for possible Workman's Compensation. Service truck and plants should have first aid kits and as many of the plant personnel as possible should have "St. Johns Ambulance" first aid instruction.

It is a "Compensation Board" regulation that any plant having (5) five or more people working as a group on any shift one of them is required to hold a "St. Johns Ambulance Certificate" in first aid. Remember, no cut or scratch is too minor to receive attention.

NOXIOUS GASES, VAPOURS ETC.

A noxious gas or vapour is one that is directly or indirectly injurious or destructive to the health and life of a human being.

They can cause explosions, asphyxiation and some are poisonous. Non-poisonous gases can asphyxiate by displacing or excluding existing oxygen in confined areas.

How is a noxious gas detected in an area? and what type of gas or gases would it likely be?

First, let us talk about entering a sewer manhole or any confined space that contains or has contained sewage that carry organic compounds or a tank where sludge is or has been stored.

Before entering these places it is necessary to test the air in the place to see if it is safe for men to enter for any reason or length of time. The person doing the testing shall be known as the testor.

In shallow manholes or tanks the air can be tested by lowering the probe of a gas sniffer through the holes in the manhole covers or through the open manhole of the tank.

In deeper manholes and tanks say of 10 ft. to 20 ft. deep or very large tanks it would be necessary to go down into the tank or manhole to get proper readings.

The testor then would be required to wear self-contained breathing apparatus and a safety harness and rope, while testing the air conditions in the manhole or tank.

Does a negative reading on the dial of the gas sniffer indicate that it is safe for entry without breathing equipment? The answer is, not necessarily. If the area being tested is small or has only the one opening the air should be sampled for oxygen content.

Supposing the testor has a reading of .5% on his dial, this is well below the (L. E. L.) lower explosive limits of any gas. Does this reading indicate safe conditions? Again no, because the gas being recorded on the sniffer gauge could be Hydrogen Sulfide (H_2S) and this gas is not only highly explosive but is very poisonous.

Let us say the testor has a high reading on his sniffer dial of 20% or more of gas to air by volume this is above the explosive limits (U. E. L.) of methane gas, a gas commonly found in such places, but it does indicate a low oxygen content.

The man or men designated to test a confined area for air conditions and safe entry should also be provided with an oxygen deficiency meter that records the actual percent of oxygen present, any reading of less than 16% of oxygen would indicate that the confined area is unsafe for entry.

The testor should also be equipped with a "Drager" meter to enable him to determine the type of any gas present.

We have discussed the method and types of meters required to test a confined area for possible air contamination by gases or vapours that can be found in such places, so now lets talk about the various gases and vapours and their effect on a man without proper protection.

A list of the types of gases that are commonly found in sewers, deep manholes and covered sludge holding tanks and digesters are:- Hydrogen Sulfide H_2S; Carbon Dioxide CO_2; Carbon Monoxide CO; Methane CH_4; and in lesser percentages Hydrogen H_2; Nitrogen N_2 and in the case of sewers there are times when gasoline, paint thinners, solvents and fuel oil are encountered.

Refer to chart No. 1 "Characteristics of dangerous gases" Item "A" Hydrogen Sulfide H_2S.

Hydrogen Sulfide gas has been placed <u>first</u> among other dangerous gases as it must be considered as the most all around dangerous gas to be found anywhere in a W. P. C. P. sewer or pumping station, and it is the gas most likely to be encountered in any of these places as it is a product of decomposition of organic matter in the sewage.

The maximum safe 8 hour exposure % by volume in air was set at 0.002% or 20 ppm but in recent years the U. S. Bureau of Mines lowered the safe 8 hour exposure to 0.001% or 10 ppm the 60 minute safe exposure has correspondingly been lowered by 0.02% to 0.01%.

Don't depend on detecting the presence of H_2S gas by smelling a "rotten egg" odour as it can be mixed with other gases that will diffuse the smell.

As per chart No. 1, exposure of 2 to 15 minutes at 0.01% impairs sense of smell. As the percentage increases, the ability to notice it by smell is completely lost.

Remember these figures, 0.01% impairs sense of smell, 0.07% to 0.1% rapidly causes acute poisoning, death in a few minutes at 0.2% or 2000 ppm.

The poisonous aspects of H_2S Hydrogen Sulfide is due mainly from the sulphur content of the gas, but since it has an equal amount of Hydrogen it is also highly explosive.

Its explosive range as per chart No. 1 is 4.3 (L.E.L.) to 46.0 (U.E.L.) as compared to Methane or natural gas at 5.0 (L.E.L.) to 15 (U.E.L.).

Notice that the most likely location of highest concentration is listed as near the bottom of a well, sewer etc., except, when the air is warm and humid, in other words on a hot humid summer day the gas could be encountered half way down or even at the top of a manhole or wet well. (Specific Gravity 1.19) = air at 1.0)

H_2S gas has another disagreeable characteristic besides being poisonous and explosive and that is corrosive. H_2S gas when saturated with moisture and in the presence of air, forms Sulphuric Acid that deteriorates cement, steel, brass gate valves and iron ladder rungs. The fumes from the presence of H_2S in the air will cause certain type of house paints to become streaked with a blackish grey colour, it will also turn bath-room sinks and tubs a dirty grey colour.

WARNING Do not, under any circumstances, enter any manhole, wet or dry well, or any confined space where there is any possibility of the presence of H_2S gas, while wearing a canister type respirator.

A canister respirator will not protect you in heavy concentrations of H_2S gas or any other type of harmful gases or oxygen deficiency conditions.

(ITEM B) on the chart is Carbon Monoxide CO, it is lighter than air (0.97) = air at 1.0) 60 min. safe exposure 0.04%, 8 hr. safe exposure 0.01%, (L.E.L.) 12.5 (U.E.L.) 74.0; unconscious in 30 min. at 0.2%, fatal in 4 hours at 0.1%.

(ITEM C) Carbon Dioxide CO_2 heavier than air (1.53) = air at 1.0) non-explosive, usually found with Methane in digester gas.

(ITEM D) Methane CH_4 Gravity (0.55) = air at 1.0) explosive range 5% (L.E.L.) to 15% (U.E.L.) volume to air mainly produced in a digester used as fuel for W.P.C.P. boilers B.T.U. Rating between 500 B.T.U. to 750 B.T.U. as compared to natural gas rated at 1000 B.T.U. per. cu. ft.

The other gases listed on No. 1 chart are to be found in manholes, sewers, and wet wells and must be guarded against for explosions and oxygen deficiencies they may cause.

As already stated, do not enter into any confined space where the air conditions are unknown without first, testing the air and never while wearing a canister type respriator, even if the air conditions are known.

Chlorine is not listed on this chart, it is listed later under the heading of "Chlorine".

In the foregoing pages it has been stated that an area or confined space suspected of containing dangerous gases is checked out by a person referred to as a testor and the equipment he must use is listed. But who is this person?

Section 12 subsection 1-5 Industrial Safety Act. 1964, Department of Labour explains.

Section 12-(1) - No confined space referred to in this section shall be tested by any person other than a compètent person.

(a) Designated by the employer.

12 (2) Every employer shall ensure that any tank, vat, chamber, pit, pipe, flue or other confined space that may be entered by any person.

(a) has a suitable manhole or other means of easy egress from all accessible parts of the confined space;

and

(b) is safe for entry.

12 (3) Where gases, vapours, mists, fumes or dusts that are likely to be dangerous to a person are present in any of the confined spaces referred to in subsection 2, or there is in the confined space a deficiency of oxygen or a temperature that is likely to be dangerous to a person, the employer shall ensure that no person enters the space unless,

(a) every practicable step has been taken to remove from the confined space such gases, vapours, mists, fumes or dusts;

(b) effective steps have been taken to prevent entry into the confined space of additional quantities of such gases, vapours, mists, fumes or dusts;

(c) the confined space has been competently tested and found safe for entry without the use of a breathing apparatus; and

(d) ventilation adequate for the safety of any person therein is provided.

12 (4) Where any of the confined spaces referred to in subsection 2 has been tested and found;

(a) unsafe for entry; or

(b) safe for entry but may thereafter become unsafe to remain in or enter unless the person is using a suitable breathing apparatus, the employer shall ensure that no person enters or remains in such confined space unless,

(c) the person is using a suitable breathing apparatus and a safety harness or other similar equipment to which is securely attached a rope, the free end of which is held by a person equipped with a suitable alarm who is keeping watch outside the confined space and who is capable of pulling such person from the confined space;

(d) the safety harness, rope and other equipment mentioned in clause C is periodically inspected by the employer and is maintained in good working order at all times;

(e) there is conveniently available a person adequately trained in artificial respiration; and

(f) the person is using such other equipment necessary to ensure his safety.

12 (5) Where a confined space has been tested and found safe for entry for a specified time but may thereafter become unsafe unless a person is using a suitable breathing apparatus, the employer shall ensure that any person who enters the space without using a suitable breathing apparatus.

(a) leaves the space at the end of the specified time; and

(b) does not re-enter or remain in the space except in compliance with clauses c, d, e, and f of subsection 4.

12 (6) Where any confined space contains any dangerous liquid or solid or is at a temperature that endangers the safety of any person, the employer shall ensure that no person enters or remains in the space unless he is using equipment or device that will ensure his safety.

SUMMARY OF SUBSECTION ONE and TWO

Subregulation 12 (1) covers the requirement that tests shall be done by a "competent person." This is not a defined term in the sense that it outlines standards by which competency can be judged but rather states:

(a) He shall be designated by the employer, Present "compètent persons" are,

1. Safety Officer

2. Assistant Safety Officer

3. Plant Superintendent

(b) His name shall be recorded on the premises and it shall be at all times available to the inspector.

Subregulation 12 (2) covers the employer's obligation to:

(a) provide means of access

(b) ensure safety for entry.

A confined space is safe for entry by either:

(a) Inherent design so that the confined space is safe to enter.

(b) Test that the confined space is safe to enter, or

(c) Rendering the confined space safe to enter and confirming the fact by tests.

The entering of confined spaces such as sewers, man-holes etc., and the regulations governing their safe entrance as defined by the Department of Labour has been discussed, but this lecture would not be complete without discussing the one big cleanout that occurs every six to eight years in plants having digesters.

DIGESTERS

At the appointed time for a complete cleanout, the following procedure is to be followed:

1. Brief all personnel involved in this work on the type of gases present, the hazards that must be considered at all times, the safety precautions to be taken and the safety equipment to be used.

2. Have on plant site all equipment required to assist in the work.

3. Methods of Procedure

NOTE: Great care must be taken from the start of this work that all sources of ignition are guarded against, e.g., sparks from tools, use or moving of equipment, smoking, wearing shoes with metal clips on the heels, etc., and leather soled shoes that are worn sufficiently to expose the shoe nails.

All personnel working on the roof shall wear rubber boots or rubber soled shoes.

All matches, cigarettes, and lighters shall be left in the men's lockers.

Smoking shall not be permitted on the ground in the area of the digester.

Non-sparking tools should be used when possible.

a) Release the stored gas pressure in the digester slowly by holding the pressure relief valve slightly open until all pressure has been expelled.

   Do not lift this weighted valve off completely until all the pressure is expelled, then lift it off and leave it off.

b) Remove all man-hole covers and leave off.

c) Start removing the contents of the digester.

d) When the man-hole covers have been removed, record explosion meter readings at the man-holes as the contents are removed.

(e) When the contents have been lowered to a point where the explosion meter readings are below the L. E. L. (Lower explosive limits) the sludge level in the digester should be around six feet below the level of the roof.

The foregoing instruction was for fixed roofs only.

Digesters having any type of floating roof the contents would have to be removed until the roof was lowered firmly onto its corbels then the same procedure would be followed as per a fixed roof. Do not release the stored gas under a gas holding floating roof until it is resting on the corbels.

DIGESTER AND COVERED SLUDGE HOLDING TANKS

Material required for complete cleanout.

Non-sparking tools

Exhaust fans (2) explosion proof motors.

Safety harness (parachute type)

Man-hoist or "A" frame with pulley, 700 to 900 lb. lift.

Steel cable, 60 ft. min. length, 1000 lb. test, (1/8"-3/16")

Two sets of flood lights

Aluminum extension ladder, 40 ft.

If compressed air is required to break up the scum blanket or concentration of settled sludge a compressor of 80 psi and at least two outlets will be required. Two lengths of galvanized pipe one 20 ft; one 12-15 ft; fittings and couplings for conversion from air hose to pipe.

All electrical equipment must be explosion proof of an approved design.

Loud sounding device must also be on hand for emergency, (Data sheet 8-14 para. 12, Department of Labour)

A self contained breathing unit of 30 min. duration.

A man in attendance with first aid and rescue training.

Note: Using Compresed Air

Compressed air can be used to dislodge and smash up thick solids in the digester.

It is far more effective than using a water hose as it homogenizes the sludge into the existing water.

Under normal conditions it is unnecessary to add any water to the contents until the tank is half empty.

The air is discharged into the digester usually through two 3/4" or 1" galvanized pipe connected to the end of the air hose.

One pipe of some 20 ft. is positioned approximately 5 ft. in front of the sludge draw-off pipe in the bottom of the tank.

The second pipe of 10 ft. to 15 ft. is used as a probe to smash up scum formations on the surface and to churn up the contents generally.

When the contents have been lowered below the half-way mark and is heavy, care must be taken that too much sludge is not moved into the draw-off sump at one time.

A water hose will also be required from this point on.

Warning

At all times when compressed air is being used in a digester, explosive mixtures of gas and air are being produced, particularly during the initial stages of sludge removal.

After the contents have been lowered 8 to 10 ft. and the air has been used constantly, the gas that was entrapped in the sludge has been released and the hazard of explosive mixtures reduced. However, when the air is again discharged into any amount of sludge after being shut off for any length of time the ratio of gas and air can be in the explosive range for a time depending on the amount of sludge present.

During the use of an air hose a greenish vapour sometimes appears at the point of air discharge into the sludge. When this occurs remove the air pipe to another location or shut off air supply until this vapour vents off.

Do not generate this vapour any more than is necessary.

Many operators have used compressed air for sludge removal and, for breaking up scum formations, without any trouble.

The hazards must be known and all safety precautions taken during the operation.

Digesters and the immediate area around them must be considered as a hazardous area at all times.

The posting of plainly visible signs should be mandatory in a plant.

"DANGER NO SMOKING" or "OPEN FLAME" signs are required at

Entrance to digester control buildings.

Digester roofs.

Ladders leading to the roof.

Digester gas compressor roofs.

Sludge truck loading pipes.

Sludge discharge pipes at drying beds.

The safety precautions, operating procedure for clean-out and safety equipment and signs recommended for digesters must also be used when cleaning out covered sludge storage tanks.

Open sludge storage tanks can also be dangerous especially during final stages of clean-out by men working in the bottom of the tank.

CHARACTERISTICS OF DANGEROUS GASES ENCOUNTERED IN SEWERS, SEWAGE PUMPING STATIONS AND SEWAGE TREATMENT PLANTS

GAS	CHEMICAL FORMULA	COMMON PROPERTIES*	SPECIFIC GRAVITY OR VAPOUR DENSITY (AIR-1)	PHYSIOLOGICAL EFFECT*	MAX SAFE 60-MIN EXPOSURE (% BY VOL. IN AIR)	MAX SAFE 8-HR EXPOSURE (% BY VOL. IN AIR)	EXPLOSIVE RANGE (% BY VOL. IN AIR) LOWER LIMIT	UPPER LIMIT	LIKELY LOCATION OF HIGHEST CONCENTRATION	MOST COMMON SOURCES
CARBON DIOXIDE	CO_2	COLORLESS, ODORLESS WHEN BREATHED IN LARGE QUANTITIES MAY CAUSE ACID TASTE. NONFLAMMABLE. NOT GENERALLY PRESENT IN DANGEROUS AMOUNTS UNLESS AN OXYGEN DEFICIENCY EXISTS.	1.53	CANNOT BE ENDURED AT 10% MORE THAN FEW MIN, EVEN IF SUBJECT IS AT REST AND OXYGEN CONTENT NORMAL. ACTS ON RESPIRATORY NERVES.	4 TO 6	0.5	-	-	AT BOTTOM; WHEN HEATED MAY STRATIFY AT POINTS ABOVE BOTTOM	PRODUCTS OF COMBUSTION, SEWER GAS, SLUDGE. ALSO ISSUES FROM CARBONACEOUS STRATA.
CARBON MONOXIDE	CO	COLORLESS, ODORLESS, TASTELESS, FLAMMABLE, POISONOUS.	0.97	COMBINES WITH HEMOGLOBIN OF BLOOD. UNCONSCIOUSNESS IN 30 MIN AT 0.2 TO 0.25%. FATAL IN 4 HR AT 0.1%. HEADACHE IN FEW HR AT 0.02%	0.04	0.01	12.5	70.0	NEAR TOP, ESPECIALLY IF PRESENT WITH ILLUMINATING GAS.	MANUFACTURED GAS, FLUE GAS, PRODUCTS OF COMBUSTION, MOTOR EXHAUST, FIRES OF ALMOST ANY KIND.
GASOLINE	C_5H_{12} TO C_9H_{20}	COLORLESS, ODOR NOTICEABLE AT 0.03%. FLAMMABLE.	3.0 TO 4.0	ANESTHETIC EFFECTS WHEN INHALED. RAPIDLY FATAL AT 2.4%. DANGEROUS FOR SHORT EXPOSURE AT 1.1 TO 2.2%.	0.4 TO 0.7	0.10	1.3	6.0	AT BOTTOM	SERVICE STATIONS, GARAGES, STORAGE TANKS, AND HOUSES.
HYDROGEN	H_2	COLORLESS, ODORLESS, TASTELESS. FLAMMABLE.	0.07	ACTS MECHANICALLY TO DEPRIVE TISSUES OF OXYGEN. DOES NOT SUPPORT LIFE.	-	-	4.0	74.0	AT TOP.	MANUFACTURED GAS, SLUDGE DIGESTION TANK GAS, ELECTROLYSIS OF WATER. RARELY FROM ROCK STRATA.

* PERCENTAGES SHOWN REPRESENT VOLUME OF GAS IN AIR.

CHART NO. 1

CHARACTERISTICS OF DANGEROUS GASES (CONTD.)

GAS	CHEMICAL FORMULA	COMMON PROPERTIES*	SPECIFIC GRAVITY OR VAPOUR DENSITY (AIR-1)	PHYSIOLOGICAL EFFECT*	MAX SAFE 60-MIN EXPOSURE (% BY VOL. IN AIR)	MAX SAFE 8-HR EXPOSURE (% BY VOL. IN AIR)	EXPLOSIVE RANGE (% BY VOL. IN AIR) LOWER LIMIT	UPPER LIMIT	LIKELY LOCATION OF HIGHEST CONCENTRATION	MOST COMMON SOURCES
HYDROGEN SULFIDE	H_2S	ROTTEN EGG ODOR IN SMALL CONC. EXPOSURE FOR 2 TO 5 MIN AT 0.01% IMPAIRS SENSE OF SMELL. ODOR NOT EVIDENT AT HIGH CONC. COLORLESS. FLAMMABLE.	1.19	IMPAIRS SENSE OF SMELL RAPIDLY AS CONC. INCREASES. DEATH IN FEW MIN AT 0.2% EXPOSURE TO 0.07 TO 0.1% RAPIDLY CAUSES ACUTE POISONING. PARALYZES RESPIRATORY CENTER.	0.02 TO 0.03	0.002	4.3	46.0	NEAR BOTTOM, BUT MAY BE ABOVE BOTTOM IF AIR IS HEATED AND HIGHLY HUMID.	COAL GAS, PETROLEUM SEWER GAS. FUMES FROM BLASTING UNDER SOME CONDITIONS SLUDGE GAS.
METHANE	CH_4	COLORLESS, ODORLESS, TASTELESS. FLAMMABLE.	0.55	ACTS MECHANICALLY TO DEPRIVE TISSUES OF OXYGEN. DOES NOT SUPPORT LIFE.	PROBABLY NO LIMIT PROVIDED OXYGEN PERCENTAGE IS SUFFICIENT FOR LIFE.		5.0	15.0	AT TOP, INCREASING TO CERTAIN DEPTH.	NATURAL GAS, SLUDGE GAS. MANUFACTURED GAS, SEWER GAS. STRATA OF SEDIMENTARY ORIGIN. IN SWAMPS OR MARSHES.
NITROGEN	N_2	COLORLESS, TASTELESS. NONFLAMMABLE. PRINCIPAL CONSTITUENT OF AIR (ABOUT 79%).	0.97	PHYSIOLOGICALLY INERT.	-	-	-	-	NEAR TOP, BUT MAY BE FOUND NEAR BOTTOM.	SEWER GAS, SLUDGE GAS. ALSO ISSUES FROM SOME ROCK STRATA.
OXYGEN (IN AIR)	O_2	COLORLESS, ODORLESS,	1.11	NORMAL AIR CONTAINS 20.93% OF O_2. MAN CAN TOLERATE DOWN TO 12% MIN SAFE 8-HR EXPOSURE, 14 TO 16%. BELOW 10% DANGEROUS TO LIFE. BELOW 5 TO 7% PROBABLY FATAL.	-	-	-	-	VARIABLE AT DIFFERENT LEVELS.	OXYGEN DEPLETION FROM POOR VENTILATION AND ABSORPTION, OR CHEMICAL CONSUMPTION OF OXYGEN.
SLUDGE GAS	-	MAY BE PRACTICALLY ODORLESS, COLORLESS.	VARIABLE	WILL NOT SUPPORT LIFE.	NO DATA. WOULD VARY WIDELY WITH COMPOSITION.	-	5.3	19.3	NEAR TOP OF STRUCTURE.	FROM DIGESTION OF SLUDGE.

* PERCENTAGES SHOWN REPRESENT VOLUME OF GAS IN AIR.

CHART NO. 1

Gas	Chemical Formula	B.T.U. Calorific Valve	Specific Gravity or Vapour Density	Explosive Limits in air % by volume		Theoretical air required for complete combustion	Minimum Ignition Temperature °Fahrenheit	Maximum Flame Temperature °Fahrenheit	Flame Speed Per Sec.	Auto Ignition Temperature
				Lower	Upper					
Methane	CH_4	913.1	0.55	5	15	9.56 to 1	1170°	3484°	0.85	1000
Natural gas		1027	0.6	4.9	15	10.00 to 1	1170°	3562°	0.99	1000
Propane	C_3H_8	2385	1.52	2.10	10.10	23.9 to 1	898°	3573°	0.95	871

Taken from Factory Mutual's Handbook of Industrial Loss Prevention.

Chapter 37

Chart No. 2

The underground pumping station was destroyed by an explosion of accumulated gases from solvents in the sewage.

The gas was ignited when the electric pump motor started on its automatic pump cycle.

NORMAL OPERATION OF THE CONVENTIONAL ACTIVATED SLUDGE SEWAGE TREATMENT PROCESS

A. R. Townshend, P. Eng.

Supervisor, Design Approvals Branch

THE ACTIVATED SLUDGE SEWAGE TREATMENT PLANT

The activated sludge process is used in competition with the trickling filter process to provide secondary treatment. The main treatment units of the activated sludge process are the aeration tanks and the final settling tanks. Re-aeration is practiced at some plants. This is done in separate re-aeration tanks after the sludge is removed from the final settling tanks, and before it is added to the sewage, or by adding the sewage at a point along the length of the aeration tanks.

In modern plants pretreatment and primary treatment are usually provided ahead of the aeration tanks.

Chlorination of the final settling tank effluent may be required by the governmental control agency which in Ontario is the Ontario Water Resources Commission.

In complete treatment plants sludge and scum removed from these processes are given further treatment in digesters and/or sludge filters, sludge drying beds, sludge lagoons, and incinerators before being removed from the plant site for final disposal.

SCOPE

This lecture deals with control of the activated sludge process under normal operating conditions. Operating difficulties of the activated sludge process will be discussed in detail at future Sewage Works courses.

The operation of screens, cutting and grinding devices, grit removal units, pre-aeration tanks, primary settling tanks, and sludge treatment units are discussed by other lecturers in this Elementary Sewage Works Course.

OPERATING CONTROL FACILITIES

The operating controls of the conventional activated sludge plant are at best comparatively limited. The operator should use to advantage what controls are provided at his particular plant.

The following control features are desirable:

1. Duplicate units which permit variation of the retention times to suit flow conditions;

2. Multiple blowers or variable speed blowers and time clock controls or adjustable weirs at mechanical plants which allow adjustment of the air supply;

3. Multiple pumps, variable speed pumps and adjustable air lifts to permit different return sludge rates;

4. Sewage, air, return sludge, waste sludge, and raw sludge flow-measuring devices which are necessary for close control of the treatment processes;

5. Laboratory equipment for conducting those control tests which are essential for efficient operation.

Unfortunately, in many cases, it is necessary to omit some of these control features in the original design in order to keep the initial, capital cost of the sewage plant project within the financial means of the owner. Laboratory equipment is one important item of plant control which can be provided by the owner at low annual cost after the plant is completed.

THE ROLE OF THE OPERATOR

The success of any sewage plant in meeting the pollution abatement requirements for which it is intended depends on intelligent application of skill and knowledge by the operator. This knowledge should include understanding of essential plant design factors and the fundamental principles upon which the various plant units are based.

At activated sludge plants the operator is better equipped to cope with emergency situations and to overcome problems which may be peculiar to his particular plant if he has a thorough understanding of the principles of the activated sludge process.

STARTING A NEW PLANT

Before starting a new plant, it is important that all tanks and piping are free of debris; that all mechanical equipment is in good working order and properly lubricated. It is good practice to check these items by first filling the tanks with water.

The next step is to pump the water out and to start the sewage flowing through the plant. It is desirable to start treatment with about one-fourth to one-third of the incoming flow, using only those portions of the plant needed to handle this flow. When the units required are filled, aeration should be commenced and set to run continuously. The sewage from the primary settling tanks should be by-passed around the secondary units for twenty-four hours. The primary effluent fed to the aeration tanks should then be increased slowly. All the settled activated sludge should be returned with none wasted. Suspended solids tests should be performed daily. When the mixed liquor suspended solids concentration reaches 400 or 1,000 ppm for mechanical*and diffused air plants respectively, the total design flow may be turned into the aeration tanks.

Normally, a good activated sludge will be produced within one to four weeks.

* - see note at conclusion of paper.

REQUIREMENTS FOR OPTIMUM EFFICIENCY

A summary of requirements for optimum efficiency is given in Table 1.

Primary settling tanks are expected to remove up to 35% of the 5-day BOD and 65% of the suspended solids in the raw sewage. A sewage treatment plant utilizing the conventional activated sludge process is expected to remove between 90 and 95% of the 5-day BOD and suspended solids in the raw sewage and to perform with reasonable stability under proper operation.

AERATION TANK OPERATION

In the operation of aeration tanks, the operator has three controls of activated sludge quality: aeration period; the volume of air supplied; and the mixed liquor suspended solids concentration.

Aeration Period

In some plants where only one aeration tank is provided, the aeration period is fixed.

Where more than one aeration tank is provided, the aeration period can be adjusted by cutting units in and out of service.

Air Supply

The actual demand of activated sludge for oxygen does not give the plant operator a useful way of determining the amount of air required. He must depend on the amount of oxygen remaining dissolved in the liquid to guide him in the regulation of the air supply.

The dissolved oxygen in the mixed liquor at the end of the aerator should not be less than 1.0 ppm by the Modified Winkler method. This is considered to be the minimum amount necessary. The optimum dissolved oxygen concentration at the end of the aerator is between 2.5 and 5.0 ppm.

It is most difficult with the high oxygen requirement at the beginning of an aerator to make a dissolved oxygen test at this point. It is practical to run the test on the liquid at the end of the tank where the demand rate is much less. It is hoped that if there is an appreciable amount of oxygen left at the end of the aeration period, the initial requirements are satisfied.

The dissolved oxygen content to be carried at the end of the aeration tanks to give best results is expected to vary from plant to plant.

Steps that may be taken to obtain this control are indicated below:

To Increase Dissolved Oxygen

1. Increase air supply by -

   (a) Increasing blower speed or use of mechanical device;

   (b) Starting an additional blower.

2. Decrease sewage rate of flow by -

   (a) Placing more aeration tanks in operation;

   (b) By-passing part of aeration tank influent to the receiving stream. (This procedure should be used only as a last resort.)

To Decrease Dissolved Oxygen

1. Decrease air supply by -

   (a) Decreasing blower speed and use of mechanical device;

   (b) Shutting off a blower;

   (c) Wasting air to the atmosphere.

2. Increase sewage rate of flow by -

   (a) Taking aeration tanks out of operation;

   (b) By-passing part or all of the raw sewage directly to the aeration tanks.

Increasing the return sludge rate raises the dissolved oxygen in the return sludge, but decreases the aeration period. This control factor must be used with discretion.

The air blown through diffusers must be clean if the diffusers are to remain unclogged for substantial periods of time. The efficiency of air application is proportional to the pressure required to drive the air through the diffuser system. The pressure loss in the diffusers increases as dust is deposited on the underside of and in the porous medium.

The air filter system should be maintained free of dust accumulations at all times. Diffuser cleaning is a difficult operation at best and is costly in time and labour. Cleaning methods such as treating with acid, caustic soda, spalling, and sand blasting can be used effectively.

Mixed Liquor Suspended Solids Concentration

Variation of the mixed liquor suspended solids concentration is the most flexible method of controlling activated sludge quality. By increasing or decreasing the amount of sludge carried, the 5-Day B.O.D. loading to solids ratio can be kept nearly constant. The process should be maintained at the ratio which gives the best adsorption-oxidation balance.

The optimum quantity of activated sludge carried will vary from plant to plant, but should be as high as possible without impairing its clarification and settling qualitites and without depleting the dissolved oxygen in the aeration tanks.

To control the mixed liquor loading necessitates the measuring of the suspended solids in the aeration tank. The settleability of the mixed liquor is measured by the

30-minute settling test. The total dry weight of the suspended solids is determined by filtering, heating, and weighing in a properly equipped laboratory or from a centrifuge test calibration curve.

These two quantities are combined in the Mohlman sludge volume index to indicate the condition of the activated sludge.

$$\text{Sludge volume index} = \frac{\%\ \text{settleable solids}}{\text{ppm suspended solids}} \times 10{,}000$$

The sludge volume index expressed as per cent solids is the Donaldson sludge density index.

$$\text{Donaldson sludge density index} = \frac{100}{\text{Mohlman S.V.I.}}$$

The maximum permissible concentration of aerator solids by the 30-minute settling test is related to the sewage flow and return sludge rate according to the following expression:

$$\%\ \text{settled volume of mixed liquor} = \frac{\text{Return Sludge Flow}}{\text{Sewage Flow} + \text{Return Sludge Flow}} \times 100$$

For a return sludge rate of 25%, the maximum permissible cylinder volume is 20%. Where a return sludge rate of 35% is possible, the 30-minute settling test should not exceed 26% by this formula.

In the above generalization it is assumed that the plant is well loaded. For special cases where the amount of air is limited, the loading is low or the aeration period is long, it is desirable to operate the aeration tanks with a lower concentration of suspended solids in the mixed liquor.

With the return sludge rate fixed at 25% and the 30-minute settling test fixed at 20%, the sludge volume index will vary with the aerator effluent suspended solids concentration. For every aerator effluent concentration there is a critical sludge volume index above which the formation of settled sludge in the final tanks will exceed the return sludge rate.

If the sludge volume index increases and an attempt is made to restore final tank balance by reducing aerator effluent concentrations (by wasting), the sludge age is correspondingly lowered and the process will fail. On the other hand, if the sewage load should rise, it is necessary to further increase the aerator solids to maintain adequate sludge age. This imposes a correspondingly higher burden on the final settling tanks. The activated sludge process is, therefore, limited by the maximum return sludge rate possible.

This relationship among mixed liquor solids, return sludge rate, and return sludge solids is given by the formula:

$(a + b) X = b y$ where

a = sewage flow in MGD;

b = return sludge in MGD;

x = mixed liquor suspended solids in ppm;

y = return sludge suspended solids in ppm;

This formula was combined with the sludge index by D. E. Bloodgood to create the accompanying nomograph for use in activated sludge plant operation. The nomograph can be used to find the maximum concentration of suspended solids that should be carried in the mixed liquor for a given desired sludge index and return sludge rate. It is evident from the nomograph that as the sludge index increases the maximum allowable suspended solids concentration in the mixed liquor decreases. It can also be used to give the required return sludge rate to maintain uniform conditions when the sludge index and suspended solids concentration in the mixed liquor are known.

Other formulas have been developed to express the inter-relationship of the variables.

The expression developed by Lamb is:

$$\% \text{ return sludge} = \frac{S}{R-S} \times 100$$

where - S = % sludge aeration tanks (30-minute settling test)

R = % sludge return sludge (30-minute settling test)

This formula is useful where only the 30-minute settling test is conducted. For example, if the raw sewage flow was one million gallons per day and the 30-minute settling tests for the mixed liquor and return sludge were 20 and 95 per cent respectively, the return sludge rate should be 27%.

The formula given by Torpey relates the settled sewage suspended solids concentration to the suspended solids concentrations of the mixed liquor and return sludge.

$$\% \text{ return sludge} = \frac{C_a - C_p}{C_r - C_a} \times 100$$

where C_a = aerator effluent suspended solids in ppm

C_p = primary effluent suspended solids in ppm

C_r = return sludge suspended solids in ppm

For example, if the respective concentrations of suspended solids are 2,500, 90 and 10,000, the return sludge rate should be 32%. If the aerator suspended solids is 2,000 ppm, the return rate should be 26%.

In order to provide some flexibility it is better not to carry the aeration liquor suspended solids at the maximum possible level since in most cases purification can be carried out at substantially the same degree at lower concentrations.

However, as stated previously, there are good reasons for carrying the solids as high as possible. High solids decrease the tendency for sludge bulking, reduce frothing nuisance, and give protection against shock loads.

FINAL SETTLING TANK OPERATION

The performance of final settling tanks is related to the condition of the sludge and to the hydraulic characteristics of the basin.

Sludge is continuously removed from the final settling tanks in order to keep it as fresh as possible. If sludge is held too long it consumes the available oxygen and progresses into a septic or anaerobic state. In sludge with a high rate of activity this may result in gasification through denitrification and floating sludge at the surface.

As shown earlier under control of aerator solids, the proper rate of return sludge to prevent undue retention can be determined from the expression:

$$\frac{\text{Return Sludge Flow}}{\text{Sewage Flow + Return Sludge Flow}} \times 100 = \%\ \text{settled volume of mixed liquor}$$

For example, if the 30-minute settling test is 20%, the quantity of return sludge should be 20% of the total flow of mixed liquor. This can be obtained easily where single tanks and meters are available.

The other rule is that the concentration of suspended solids in the return sludge must never be allowed to exceed the sludge volume index expressed as per cent solids. (The Donaldson sludge density index) Thus the maximum permissible concentration of return sludge would be 4,000 ppm for a sludge volume index of 250 and 10,000 ppm for an index of 100.

Whichever control method is used, the sludge depth should be checked by soundings at least once a week. The sludge blanket in the final settling tanks should not be allowed to exceed 2 feet in depth.

Density currents are induced in final settling tanks due to the fact that the specific gravity of the sludge mixture is greater than the clarified water in the tank. The activated sludge on entering the settling tank

falls almost vertically and then flows along the bottom of the tank, toward the outlet end. Currents near the bottom of the tank will establish secondary currents in the water layers above them in a reverse direction. This phenomenon will lead to a carry-over of sludge in the weirs from upwelling currents unless adequate weirs and baffles are provided.

Actual plant operation may indicate the need for weir relocation, increased weir length, and alteration of the inlet devices. Adequate baffling is also required to prevent surface short circuiting.

SECONDARY SLUDGE WASTING

Waste activated sludge should be adjusted to keep the 30-minute settling test within the desired range. Where fluctuations make this control procedure difficult, the level of the sludge blanket in the final settling tanks should be used as a guide to sludge wasting. The level generally should not exceed one to two feet above the bottom of the tank.

At some plants, control is accomplished by wasting continuously. At other plants, it is necessary to adopt a wasting schedule so that small amounts are wasted slowly and uniformly during periods of low flow. Where the sludge is wasted to primary settling tanks this tends to improve the quality of the primary effluent.

Large volumes should not be wasted at one time. This reduces the 5-Day BOD to solids loading or sludge age and encourages rapid growth of the remaining activated sludge. If the primary settling tanks are not able to handle the loading, the sludge will be carried back into the aeration tanks and the wasting operation will be ineffective.

FINAL SETTLING TANK EFFLUENT

If all goes well the final settling tank effluent should be clear and sparkling in appearance. Suspended floc particles should be absent.

It is the objective of the OWRC that treated effluents from activated sludge plants contain no more than 15 ppm of 5-Day BOD and suspended solids. This is possible with good operation where the raw sewage strength does not exceed 250 ppm 5-Day BOD and suspended solids.

NORMAL OPERATION

OF THE CONVENTIONAL ACTIVATED SLUDGE

SEWAGE TREATMENT PROCESS

Summary of Requirements for Optimum Efficiency

Item	Requirements

Micro-organisms

A varied culture of different types of bacteria with Zoozlea ramigara and/or other gel formers present:

Stalked, ciliate protozoa and free-swimming ciliates present without the smaller flagellate protozoa;

Absence of the fungus, Sphaerotilus natans.

Feed Characteristics

The raw sewage be predominantly composed of a mixture of soluble, colloidal and suspended materials; soluble BOD being more difficult to process especially at lower temperatures;

For average domestic sewage the feed contain between 8 to 18 ppm free ammonia as N and between 1.7 and 2.8 ppm phosphorus as P;

The raw sewage be free of toxic materials.

Temperature

Optimum temperature of 82°F.

pH

Between 7.0 and 7.5

Air Requirements

(a) 0.5 to 1.5 cu. feet of free air per gallon of sewage;

Air Requirements (Cont'd)

(b) 500 to 700 cu. feet per lb. BOD removed when BOD loading 25 to 30 lb. per 100 lb. aerator solids;

(c) 700 to 1,750 cu. feet per lb. BOD removed when BOD loading 25 to 12 lb. per 100 lb. aerator suspended solids.

Aeration Period

(a) Diffused air - 5 to 7 hours;

(b) Mechanical*- 8 to 10 hours.

Sludge Age

3 to 4 days

BOD Loading

(a) 25 to 30 lb. of BOD per 1,000 cu. feet of aeration tank;

(b) 30 to 40 lb. of BOD per 100 lb. of aerator suspended solids for large plants;

(c) 20 to 30 lb. of BOD per 100 lb. of aerator suspended solids for small plants.

Sludge Quantity

(a) 1,500 to 3,000 ppm aerator suspended solids for diffused air plants;

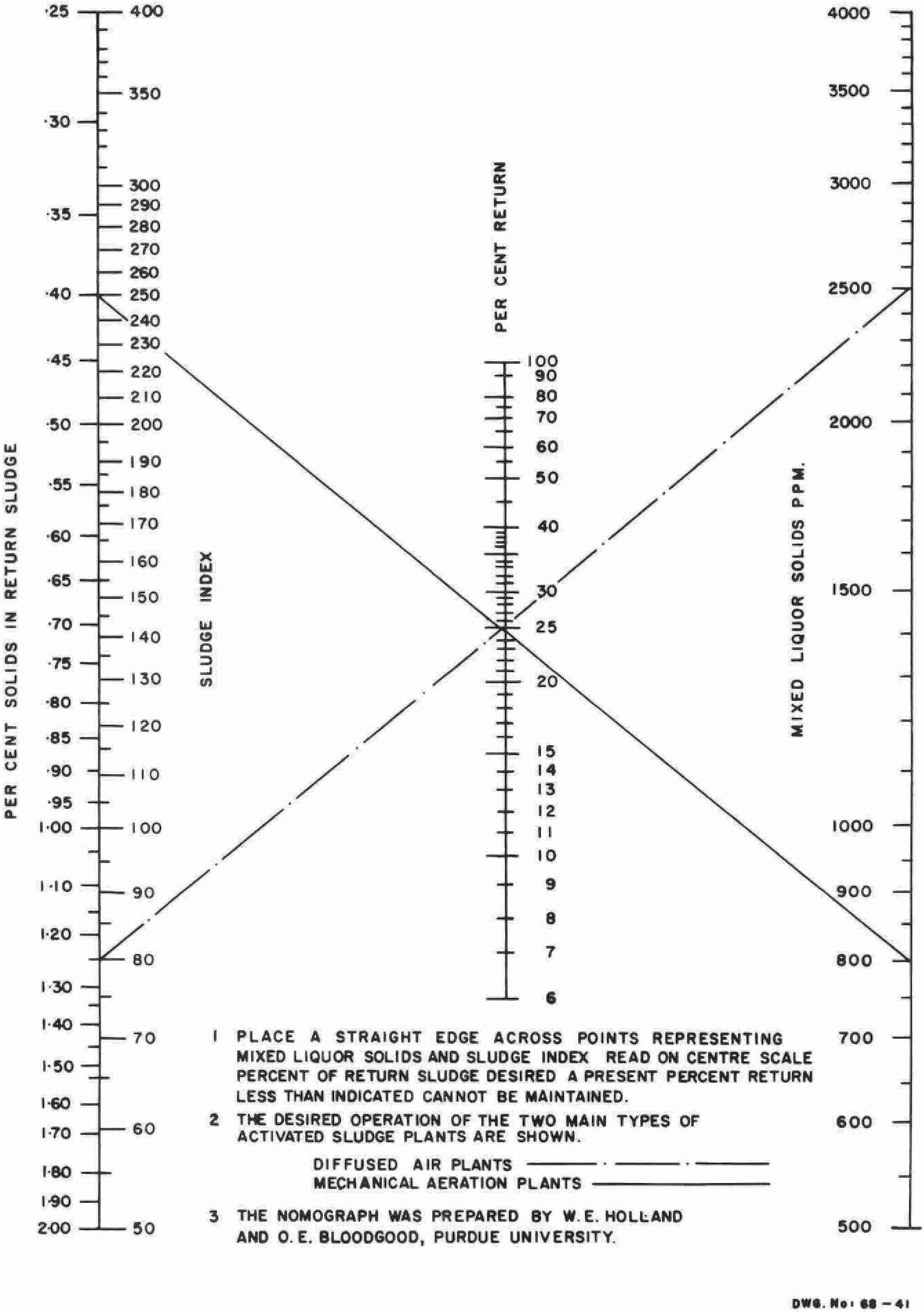
(b) 500 to 1,200 ppm for mechanical*aeration plants.

Sludge Quality

Volatile matter	-	60 to 85 % of total aerator solids
Alkalinity	-	100 to 200 ppm
Dissolved Oxygen	-	
Content at outlet	-	2.0 to 5.0 ppm
30-minute settling test	-	15 to 25%
Sludge Volume Index	-	(a) near 100 for diffused air plants; (b) about 250 for mechanical aeration plants*.

* NOTE: Modern mechanical aerators of the turbine and high intensity cone type are equivalent to diffused air systems. Earlier mechanical aerators of the splash plate type, for example, were less efficient requiring longer aeration periods and lower mixed liquor suspended solids concentrations. In this paper "mechanical aeration plants" refer to those with the less efficient types of aerators.

NOMOGRAPH FOR USE IN ACTIVATED SLUDGE PLANT OPERATION



1 PLACE A STRAIGHT EDGE ACROSS POINTS REPRESENTING MIXED LIQUOR SOLIDS AND SLUDGE INDEX READ ON CENTRE SCALE PERCENT OF RETURN SLUDGE DESIRED A PRESENT PERCENT RETURN LESS THAN INDICATED CANNOT BE MAINTAINED.

2 THE DESIRED OPERATION OF THE TWO MAIN TYPES OF ACTIVATED SLUDGE PLANTS ARE SHOWN.

DIFFUSED AIR PLANTS —— · —— · ——

MECHANICAL AERATION PLANTS ————

3 THE NOMOGRAPH WAS PREPARED BY W. E. HOLLAND AND O. E. BLOODGOOD, PURDUE UNIVERSITY.

DWG. No: 68 – 41

BASIC CONSIDERATIONS OF THE CONVENTIONAL ACTIVATED SLUDGE TREATMENT PROCESS

G. H. Kay

Supervisor, District Engineers Branch
Division of Sanitary Engineering

After primary treatment, usually by sedimentation, settled sewage still contains organic solids which are putrescible and can result in odourous gases and unsightly conditions, together with associated pressures on the receiving stream. These solids may be in a suspended, colloidal or dissolved state and may constitute forty to fifty percent of the original suspended solids and sixty-five to seventy-five percent of the original BOD, depending on sewage qualities and the efficiency of the primary sedimentation unit. As our municipalities grow, this becomes an excessive amount for the receiving streams to assimilate and efficient means of secondary type treatment had to be found.

In their initial form, the organic solids do not lend themselves readily nor economically to normal physical or mechanical methods of removal.

BIOLOGICAL PROCESSES

In biological processes, bacteria and other microbial life were known to be capable by using the material concerned in their life processes, of breaking down some complex organic substances, first into simpler, less putrescible organic compounds of nitrogen phosphorous and sulphur and finally to the more stable nitrates, phosphates and sulphates together with some gases and water. It was also known that if these processes took place in the presence of oxygen, the process was inoffensive. Without this dissolved oxygen, the process was accompanied by objectionable gases and unsightly conditions. The processes under consideration were usually of the first type (aerobic).

Therefore, since the solids of sewage are also organics comprised of carbohydrates, proteins and fats, together with bacteria and other micro-organisms, it was considered that the settled sewage could be treated by trickling filters or by plain aeration for a long period of time in fill-and-draw (fill-and-empty) operations, to completely stabilize or oxidize it. This latter process commonly required five weeks compared to the much shorter periods required by the biological or trickling filters and prompted further aeration process experimentation at the turn of this century.

HISTORY

In 1913 in Manchester England, while utilizing this fill-and-draw aeration method, Ardern and Lockett discovered that if a portion of the relatively stabilized deposit or sludge remaining in the bottom of the aeration unit was left there to mix with the next batch of sewage, the purifying process was accelerated, and the time required for purification was reduced. This acceleration increased with each further increment of retained sludge added to each new batch of sewage, up to a limiting value, when the sewage was stabilized or oxidized after 24 hours of aeration time. This was a real improvement over the five weeks usually required for plain aeration, and Ardern and Lockett properly assumed that the acceleration and the associated reduced aeration time required, was attributable to some faculty of the "activated" deposit or sludge.

DEVELOPMENTS

It was but a short time before flow-through units were evolved wherein this "activated" deposit or sludge was settled in a separate unit and returned rapidly to the aeration unit, while the sparkling effluent was safely discharged to a watercourse. The improved efficiency possible then allowed this process to commence to compete with the trickling filters which were then in general use.

Subsequent designers eagerly seized this improved method of secondary type sewage treatment but then as now, some aspects of the process were not completely understood, and for a long time basic considerations produced almost standard units having the following aspects:

Primary settling period - 1 hour

Aeration contact period - 4-8 hours

Suspended solids concentration - average 1500 ppm

Quantity of air required - 0.5 - 2.0 cu. ft. per gallon of sewage

Final settling period - 2 hours

Quantity of the return sludge - 10-30% of sewage flow

Lacking a full knowledge of the mechanics of the process, a designer could provide a plant using these design guides which could be made to operate reasonably well for average sewage strengths, providing that flows do not regularly exceed design flows. However, with the variation in sewage strengths and flows, and the demand for consistenly high efficiencies, serious operating problems arise.

INVESTIGATIONS

Extensive investigations performed during the last fifteen years have affirmed the true biochemical nature of the activated sludge process and have assisted in deriving new, more proper controls and modifications for efficient operations.

BACTERIOLOGY

Generally, it has been shown that in an activated sludge process, the clarification of settled

sewage and the removal of the organic pollutants thereof, is effected by the life processes of bacteria which predominates the activated sludge. The many varieties of these, including the slime-producing bacteria, Zooglea Ramigera, are primarily responsible for the biological oxidation, to stable compounds, of the nutrients in the sewage with the subsequent physical change and clarification thereof. There are many varied organisms each with its own role to play. As the bacteria are able to utilize human wastes, so other organisms in the activated sludge mass are able to utilize the waste from the bacteria. If the sewage is heterogeneous, (containing many varied constituents), the activated sludge colony is also heterogeneous. If one nutrient predominates, one organism, specie or strain will grow to predominance.

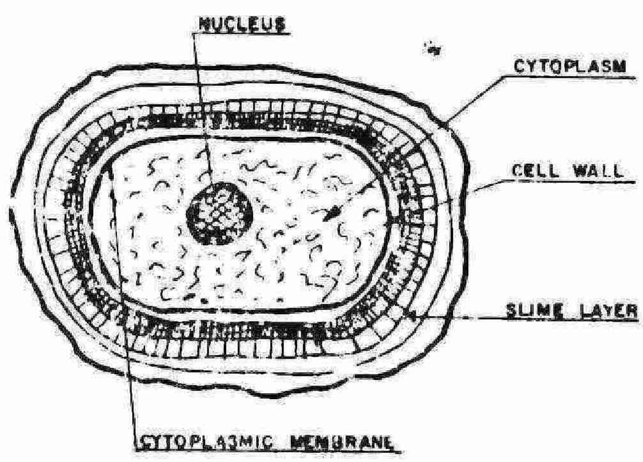


FIG. 1 – Schematic Diagram of a Bacterium

Figure #1 shows a bacterium surrounded by a slime layer. In the process of violent mixing at the head of the aeration tank, the finely divided and colloidal particles of the sewage are trapped or adsorbed onto this slime and the enlarged unit strikes and joins others to form feathery flocs. These also act as sieves and entrap more material to yield the active sludge mass in the aeration unit. The biological flocculation therefore acts similarly to the flocculation at water treatment plants via various forces, to remove for sedimentation, the microscopic particles in the water that are not easily otherwise removed.

As Mr. Vlassoff has said, the bacteria must have the nutrient pass through the cell wall to the inner cytoplasm (protoplasm) in order to be utilized, and if you remember his drawing, you can see that violent mixing is required, so that the nutrient particles may find a path into the cell. This mixing also continually breaks up these flocs so that each organism, be it on the surface or in the centre of the floc mass, may have a proper intimate oxygen supply for the support of its life process. This also drives off waste gases such as CO_2 produced by the bacteria and which would be toxic to them. The dissolved nutrients are soon drawn into the cell by absorption processes but the suspended and colloidal portions that are trapped or adsorbed in the slime layer are first acted upon by extra-cellular enzymes exuded by the cell, before being absorbed therein. Intra-cellular enzymes further prepare the material for use by the bacteria in its life processes or metabolism (by oxidation) and production (by synthesis) of new protoplasm and cells.

SLUDGE CONDITIONING

The process of absorption of dissolved material and the entrapping or adsorption of suspended and colloidal material for future utilization, is usually completed within one-half hour and the sewage will then clarify and, partly because of the entrapped and relatively heavy solids, the sludge will often settle properly. However, in

the closely following rapid growth phase, the increased quantities of protoplasm in the individual cells reduces their density and therefore deteriorates their settling properties. To produce a good effluent, it is necessary to adequately separate the sludge from the liquid to be discharged. There is little advantage in having a mixture that will clarify, if it requires such a long time to do so, that large expensive final settling tanks are required. Also, in its present form the sludge is not considered to be truly effective for future solids removal as, with its adequate stored food or energy, the cell itself is not capable of readily clarifying more sewage by adsorbing more solids, when returned to the head of the aeration tank. Therefore, for both of these reasons, prior to discharge to the settling tank, the mass of activated sludge is retained under optimum aerobic conditions (aerated) while the processes of biochemical oxidation proceed to improve its settling and clarifying properties by reducing this stored food and extra bacterium size. In the conventional activated sludge process, this aeration should continue until the sludge has spent a period in the "death" phase which will be discussed later.

BIOLOGICAL OXIDATION CURVE

In all biological oxidation processes wherein:

1. The environment is completely aerobic (adequate oxygen),
2. Conditions are optimum with regard to temperature, toxicity and pH at all times,
3. The environment (sewage) contains all of the essential nutrient elements required for biological growth,
4. A definite, initially abundant amount of food is available,

The number of bacteria will alter in a manner resembling the curve in Figure #2.

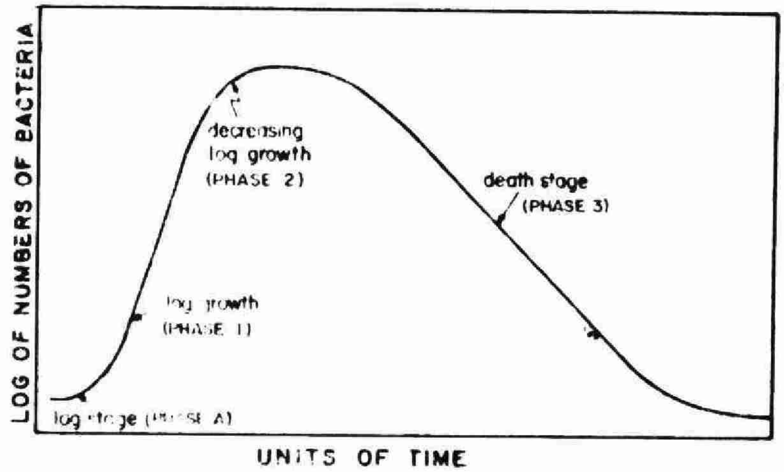


FIGURE 2 — Growth phases in biological oxidation processes

This is the general curve for all biological oxidation processes where these conditions exist, and indicates how the numbers of bacteria or sludge mass tend to increase and then decrease with the passage of time or, similarly, as the sludge mass progresses down a conventional aeration tank. This is the curve of the biological growth that occurred in Ardern and Lockett's initial fill-and-draw aeration experiments and would approximate the sludge mass growth in an underloaded flow-through aeration tank not employing activated sludge and having a sewage flow relatively constant in quality and quantity. Naturally, the specific curve applicable in any process would be a function of the

predominant micro-organisms, the sewage's chemical composition, temperature, etc., and in part that is why specific units of time and specific units of baterial numbers are not shown on the graph.

However, using this general curve which is common to each, it has been observed that without the correct addition of "acclimatized" or "activated" sludge, an inactive phase or "lag stage" occurs when no appreciable growth in bacterial numbers or masses occurs with the passage of time, apparently while the micro-organisms "acclimatize" themselves to the food supply (organic solids) of the sewage.

LOG GROWTH (PHASE I)

I am indebted to Mr. Vlassoff for his excellent presentation on the "Bacteriology of Sewage Treatment" and I would refer you again to his paper.

He has indicated that the bacteria utilize some of the stored sewage nutrients in their regular life processes (metabolism) through oxidation, giving off as waste products, CO_2 and water. Some of the stored nutrient is also used in producing or synthesizing more cell material or protoplasm (similar to photosynthesis in plants). The bacterium enlarges in size and finally splits to form two duplicate bacteria which then progress to repeat this process. Under the optimum conditions previously mentioned, this increase in numbers takes place at a maximum rate of growth or log growth rate with the associated maximum rate of BOD reduction. It is limited only by the mean (average) generation time of the system. This is the time for a bacterium to grow to full size from the time of splitting (fission), or approximately 20 minutes. Some investigators feel that this time for a bacterium to develop and completely divide into two cells is extended by existing inadequate aeration processes. During this growth stage, approximately 57 percent of the BOD removed is synthesized or converted into new cell material. Forty-three percent is used or oxidized in the cell's basic life processes (metabolism).

DECREASING LOG GROWTH (PHASE II)

At a certain point in this phase, the food as represented in this case by the nutrient value of the sewage, is inadequate to support this rapid increase of bacterial masses and results in a decreased rate of growth (decreasing log growth) proportional to the food remaining. Ultimately, at approximately the top of the curve, this supply becomes only adequate to maintain the natural life or metabolism of the existing bacteria and growth approximately ceases.

DEATH PHASE (PHASE III)

As aeration continues, eventually this supply becomes further reduced and the bacteria commence to absorb the protoplasm of their own bodies by auto-oxidation as humans might utilize their fat layers, and if continued, will result in the death of the cell. This therefore is called the "death phase". This utilization or reduction of the protoplasm increases the density of the masses and so assists in later sedimentation. On the graph this phase of decreasing masses is represented by that portion to the right of the top of the curve. Extended aeration time, as in the misnamed total oxidation process, is required to effect almost complete reduction of the sludge masses as indicated by the right end of the graph.

ACTIVATED SLUDGE CURVE

In an activated sludge process, the elimination of the lag phase by the addition of large numbers of acclimatized or "activated" bacteria to the head of the aeration tank, yields a curve as shown in Figure #3. Also, since the receiving stream is capable of assimilating some BOD represented now by the sludge mass, and since some of the sludge is wasted to the primary tanks for more economical disposal in anaerobic digesters, the sludge mass is not subjected to the aforementioned extended aeration.

Therefore, this phase, represented by the extreme right end of the graph (Figure #2) is usually not applicable to the sludge mass in the conventional process. Subsequently, the conventional activated sludge process generally confines the micro-organism colony to a phase straddling the top of this curve (Figure #3).

Now, if this drawing can be borne in mind, the causes for changes in the operations at any conventional activated sludge plant and at any plant using a modification thereof can be better understood.

The conventional plant is best operated to keep the microbial concentration actively growing at the head of the aeration tank to provide rapid clarification by adsorption and absorption of the solids with oxidation and synthesis of the stored material progressing as the sewage flows down the tank, including a period in the auto-oxidation or death phase to improve the settling and later adsorptive or clarification properties of the sludge.

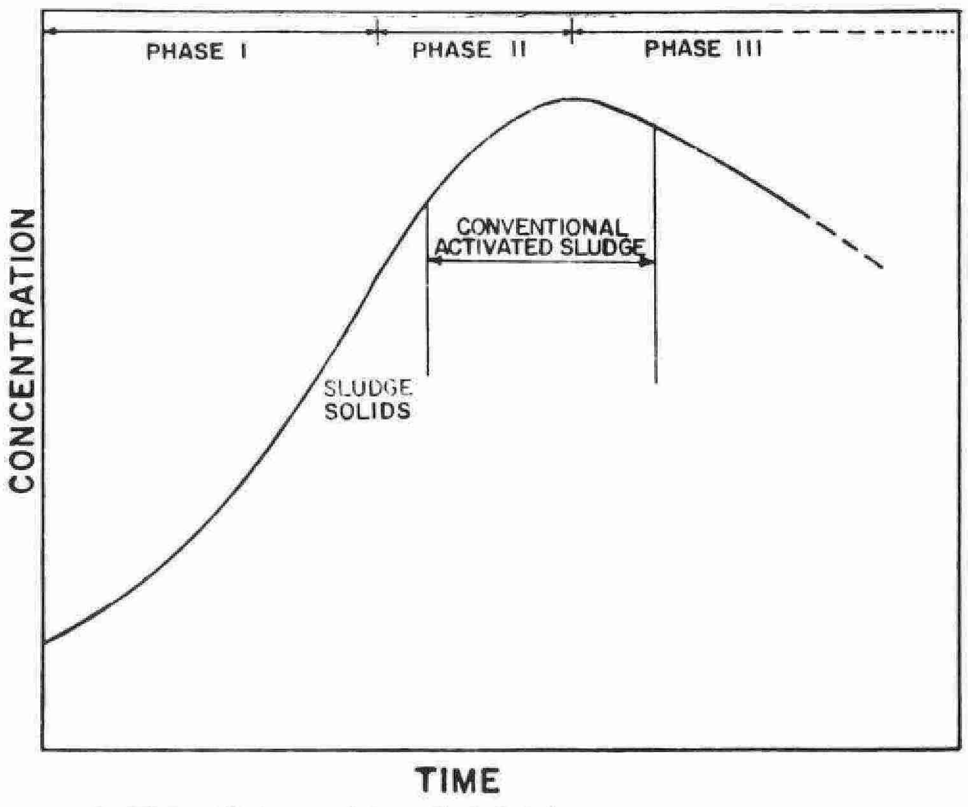


FIGURE 3 — Sludge growth for activated sludge.

CURVE CHANGES

If a toxic material is added to the regular sewage the lag stage may re-appear. If a greater quantity of food becomes available, (pounds of BOD, primarily of the sewage organic solids) or if a period of hydraulic overload occurs, the sludge mass will not have been in the auto-oxidation phase long enough to produce a quick settling, highly absorptive sludge (i.e., the plant is overloaded).

If a comparatively lesser quantity of food becomes available (pounds of BOD) or if hydraulic underloading occurs, the sludge will have spent an excessive period in the auto-oxidation phase and although the sludge will be relatively heavy and settle rapidly, those cells that are almost completely oxidized or mineralized, tend to float out to spoil the effluent quality. The remaining returned activated sludge tends to be less active for subsequent sewage clarification.

Similarly, the curve characteristics will change with severe changes in aeration tank solids concentrations.

F:M OR FOOD-TO-MICRO-ORGANISMS RATIO

In summary, following adsorption and clarification, the growth-synthesis portion of the process must be kept in balance with the auto-oxidation-death portion, to keep the sludge masses actively growing and subsequently self-consuming as they pass through the aeration unit in removing and utilizing the putrescible organic solids in the sewage.

Therefore, primarily, a given quantity of food in the form of organic sewage solids will properly support the life of a given quantity of active micro-organisms for the process.

And so the theory of food-to-micro-organisms or BOD to sludge solids relationship gains predominance.

For a given sewage strength and sewage flow (pounds of organic solids or more correctly pounds of BOD) there must be a proper micro-organism balance (pounds) based on these concepts.

To provide a vessel for this action, the designers have found that the concept of approximately 35 pounds of BOD per 1000 cu. ft. of capacity is a proper value to use in calculating aeration unit capacity. In the F:M or food-to-micro-organism relationships, Hazeltine has shown that a loading of 35 lbs. of BOD entering the aeration tank per 100 lbs. of sludge solids (representing active organisms) has proven to be efficient, while values of 0.20 to 0.40 have also been used.

This is basically the reciprocal of the Sludge Age of 3-4 days proposed by Gould and Edwards. Due to the varied composition of sewages, care must be taken not to compute aeration tank suspended solids as being totally active organisms. The use of organic (volatile) sludge solids values in computations as representing active organisms, is an improvement and perhaps a computation based on free nitrogen would be more correct.

Therefore, knowing the average strength and flow rate of the settled sewage, the optimum range of aeration tank suspended solids for best operating efficiencies is known and return sludge wasting rates must be adjusted to keep these solids within this range.

Due to the growth of the bacteria in utilizing sewage nutrients, there will be a tendency for excess sludge to build up in the final settling tank where it may tend to decompose. There will be approximately 0.5 lb. of growth of the sludge mass for each pound of BOD stabilized. This must be removed from the system and is accomplished by wasting sludge to the primary settling tank for subsequent disposal.

SLUDGE SETTLING CHARACTERISTICS

As previously stated, an efficient final sedimentation tank and a rapidly settling floc are necessary. In previous lectures you have discussed the 30-minute settling test, the sludge volume index (S.V.I.) or Mohlman Index, and perhaps the Donaldson Index or 100/S.V.I. The settling characteristics of the sludge as we have shown, primarily will be dependent upon the stored energy or food level thereof and therefore, generally depends upon the phase of the biological oxidation curve that applies to the sludge as it enters the sedimentation unit. In other words, after 30 minutes settling the sludge may appear compact or fluffy depending upon the relative quality of stored energy or protoplasm. The quantity that settles in 30 minutes will be a function also of the concentration of sludge solids in the system. Therefore, at a given sludge return pumping rate the weight of solids or active micro-organisms therein, will be a function of these two factors which are included in the sludge volume index or Mohlman Index and the Donaldson Index = 100 /S.V.I., and in part this value indicates the life phase on the biological oxidation curve of the sludge entering the final sedimentation tank. A proper value here generally suggests that the sludge has entered the death phase and will ordinarily have settling characteristics conducive to producing superior effluents.

Due to the inter-relation of these factors, it has been found that the concentration of suspended solids in the return sludge should never be allowed to exceed this sludge density index (Donaldson Index) expressed as percent solids. For example, the maximum permissible suspended solids concentration of the return sludge would be approximately 10,000 ppm for a Mohlman Index of 100.

Together with the defined F:M ratio and the known optimum sludge index ranges these new guides suggest that the maximum return sludge rate possible at any plant due to unit capacities there is important. Mr. Townshend will be presenting pertinent formulae and providing a nomogram that will offer a visual assessment of these inter-relations.

BASIC COMMENTS

For a certain sewage strength, (pounds of BOD) the organisms remove the putrescible solids and settle most rapidly for subsequent removal, within certain aeration tank solids concentrations. The rate of sludge wasting must be adjusted to maintain these concentrations.

The rate of sludge return is adjusted to prevent a build-up in the final settling tank of the increased cell solids produced from the nutrients of the sewage by the organisms in their natural life processes.

We can now see that the air in the process is added to provide the living organisms with adequate oxygen to perform their normal life processes and must not be allowed to fall to a value that will restrict the process's efficiency.

MODIFICATIONS

There are several modicications of the process to make it more efficient or economical, but each of these is really only adjustments in the life cycle of the micro-organisms in the activated sludge colony, to take advantage of certain definite physical and biochemical properties thereof. A common modiciation is the so-called total oxidation process, where an extended aeration period prolongs the period that the bacteria are in the death phase where they are experiencing auto-oxidation, in an attempt to minimize the amount of sludge that will require ultimate disposal.

SUMMARY

It has been said that "The micro-organisms and the tiny macro-organisms are the real operators of sewage treatment processes; the function of the human operators is to furnish optimum environmental conditions required by the biological life". If we will bear this general thought in mind we may be more able to deal efficiently with the ever-increasing quantities of sewage requiring adequate secondary treatment before ultimate disposal to our watercourses.

PROBLEMS CAUSED BY INDUSTRIAL WASTES IN SEWERS AND SEWAGE PLANTS

T. D. Armstrong
District Engineer
Division of Industrial Wastes

As operators at sewage treatment plants, I am sure you have all experienced the problems that can be caused by industrial wastes. In fact, you have probably thought that life would be very simple if it were not for the occasional slugs of grease say, that send you scurrying for skimming buckets and cause you to work overtime. You may damn this problem when it occurs, but let us examine the situation more thoroughly. Any one of you can operate a plant under ideal conditions but how many of you have the foresight and ingenuity to circumvent problems, such as those resulting from industrial wastes, and still keep the plant from becoming upset? You who can, regardless of whom you are working for, are reliable and valuable employees.

It is customary for a municipality to enact a sewer-use by-law in an attempt to control the characteristics of the waste flows being discharged to the sanitary system. If industries comply with this by-law, there should be no problems either in the sewers or at the plant. The salient features of such a by-law are that discharges must have the following characteristics:

1. temperature - not greater than 150°F.
2. pH - between 5.5 and 9.5
3. organic loading as measured by the biochemical oxygen demand (BOD) - not greater than 300 parts per million (ppm).
4. suspended solids - not greater than 350 ppm.
5. toxic materials should not exceed the following levels:

cyanide as HCN	-	2 - 5 ppm
phenols	-	0.1 - 1.0 ppm
sulphides as H_2S	-	2 - 5 ppm
metals	-	3 - 10 ppm

6. oils and greases or those substances soluble in ether -

    (a) of mineral origin - not greater than 15 ppm
    (b) of animal or vegetable origin - not greater than 100 ppm.

7. there must be negligible quantities of explosive, inflammable and/or radioactive materials present.
8. flow volumes must be such that hydraulic overloading of the system will not result.

It may be noted at this time that the effect of any one industrial discharge on the entire sewage flow will be proportional to their relative volumes. As most industrial wastes are amenable to treatment with domestic sewage in municipal treatment plants, it may be possible for a municipality to accept and treat wastes that do not comply with the by-law limits and still not upset the operation of the sewage treatment plant. The municipality may wish to supply this additional service at no extra charge or they may require a special agreement with the industry and additional money for this service. Normally there is a section in the by-law that makes provision for this arrangement. In order that the municipality may decide how to handle any particular situation, they must know the probable effect of any waste flow on their sewers and sewage treatment plant.

An industry views the treatment and disposal of its wastes as a matter of strict economics. It expects and deserves treatment of flows within the by-law limits for the normal sewer rate charge. If the municipality will accept a higher strength waste for a sum less than that needed to pretreat the wastes to by-law limits, it is good business for the industry to use this method of disposal. Many times the full strength waste cannot be treated at the municipal plant and it is then up to the industry to pretreat to a level which is acceptable to the municipality and economical to the industry. It is quite often easier to remove contaminants from a waste flow at the source within the industry, and this should be done where possible. It must be emphasized however, that the responsibility for ensuring that wastes from an industry are treated to the required level remains solely with the industry.

The problems that may be anticipated in sewers from flows not in compliance with sewer-use by-laws may be outlined under the following headings:

1. Flows - Excessive or fluctuating flows may overload the hydraulic capacity of a sewer and cause backing up of sewage into basements, or overflowing at pumping stations.

2. Temperature - The higher the temperature of a waste discharge the greater the biological activity in the sewer (rate doubles for every $10^{o}C.$ rise). Thus the oxygen supply is quickly depleted and septic conditions occur. Also, high temperatures accelerate corrosion and place thermal stresses on the sewer pipes and joints.

3. Suspended Solids - May settle in the sewers and cause blockage.

4. pH - Variance beyond the acceptable limits will result in corrosion of the sewer.

5. Oils and greases will build up on the inside of the lines and reduce the sewer capacity.

6. Dissolved Salts - Certain dissolved salts may precipitate out in the sewers and lead to blockages and/or corroding conditions, e.g., $Fe\ SO_4 + Ca(OH)_2 = CaSO_4 + Fe(OH)_3$

More important from the sewage treatment plant operator's point of view, however, is the effect of industrial waste discharges on the operation of the sewage treatment plant. The operator must consider himself somewhat of a doctor in that he must first of all note the symptoms, then diagnose the type and extent of the illness and assess the effect it will have, or has had, on the various processes. Finally, and most important, he must take quick remedial action to offset the changing conditions. The various characteristics of industrial waste discharges that are of concern to a sewage plant operator will be covered under the headings:

(a) detection
(b) effect on:
  1. primary section
  2. biological processes
(c) corrective action that may be taken.

1. Flow - excessive or surging flow conditions may be noted on the flow measuring devices within the plant or simply by the level of the flow on the walls of the channels. High flow rates will tend to flush the various tanks out and thus affect the detention times and the treatment provided. Little can be done to alleviate this condition at the sewage plant, as it should be corrected at the industry where the flows may be equalized.

2. Temperature - the rate of biological activity increases with temperature in a waste flow and the resulting septic conditions may be noted by the smell and low dissolved oxygen content of the raw sewage at the plant. A septic sewage will cause septicity in the primary clarifiers and exert an increased oxygen demand in the secondary biological section. The action required in this case would be to pre-aerate or pre-chlorinate the raw sewage flow.

3. pH - a waste with a pH outside the accepted range (5.5 to 9.5), in addition to creating corrosive problems throughout the plant, will tend to impair the settling and biological processes. This condition may be noted by checking the waste flow with pH paper at regular intervals and again little can be done at the plant as the situation should be corrected by having industry neutralize its wastes prior to discharge.

4. Organic loading (biochemical oxygen demand - BOD) - high strength industrial discharges will show up in the 5-day BOD test but this is of no assistance to the operator who is concerned with the conditions at any given moment. These high strength wastes are usually characterized by an unusual colour (e.g., red; indicating blood, dye, etc.), smell (e.g., a septic smell because of the rapid depletion of oxygen in the sewer lines) or the inclusion of tell-tale solids (feathers, hair, etc.). If the high strength is due mainly to dissolved components, it will have little effect on the primary section, but will create a high oxygen demand

and extreme sludge growth in the secondary biological section. If due to suspended matter, additional quantities of sludge will accumulate in the primary tanks and the digesters may be taxed beyond capacity. The action that should be taken at the plant would include carrying a higher concentration of solids and air in the aeration section and the possible addition of alkaline materials to the digesters as well as additional hauling of digested sludge so that a correct environment may be maintained for the anaerobic decomposition process.

5. Suspended solids - this characteristic of the waste flow is one of the most recognizable and usually a close examination with the naked eye will reveal unusual conditions which should be taken into account. The majority of the particles in suspension should settle out in the primary settling tanks and while most will be amenable to anaerobic treatment some such as clay, chicken beaks, hair and bark will decompose very slowly and thus use additional digester capacity. Adjustment in digester operation as well as cleaning of the digesters may be required if these solids are allowed to get through the preliminary screening devices.

6. Toxic materials - toxic materials such as copper, chromium, phenols, etc. may be difficult to detect in the raw sewage if they are in low concentrations. Should either the aerobic or anaerobic biological section be upset, however, toxic materials should be one of the first suspects. A laboratory analysis is required to confirm any suspicion in this regard. Higher solids could be carried in the aeration section to help in preventing an upset.

7. Oils and greases - these ether soluble materials will usually come to the surface in the grit tanks and primary clarifiers and their presence is thus readily apparent. If they can be skimmed, either by means of the regular skimming facilities, or manually, they should have little effect on the operation of the plant other than to deface the areas to which they cling.

It may be noted that in most cases, sophisticated laboratory equipment is not a necessary part of good sewage plant operation. More important is the ability of the

operator to adapt his thinking to the situation at hand and to take proper remedial action.

A resourceful operator should not only operate the plant as well as possible, but should also note the time and conditions of any upsets at the plant. He should then attempt to determine the section of the system from which the upsetting discharge came and to define as closely as possible the problem industry. Armed with this information the municipal officials, after investigating conditions at the industries in the area, should be able to locate the culprit and thus be in a postion to enforce their sewer-use by-law.

SUMMARY

If, as a sewage treatment plant operator, you can operate a plant well under adverse conditions such as extreme industrial waste loading, you have reason to feel proud. The more high strength wastes that can be treated in your plant without process upset, the better service your employer is providing. Just remember, if you recognize the type of waste you are getting and how it may affect the plant, then you will have a chance to adapt the operation to treat it with a minimum of problems.

DIGESTION OF SLUDGE

G. R. Trewin

Assistant Director
Division of Sanitary Engineering

PURPOSE

A primary purpose of sludge digestion is to reduce the complex organic matter present in the raw sludge removed by sedimentation processes to a simpler non-objectionable state. Digestion produces a sludge more amenable to dewatering, without nuisance, and renders the sludge fit for easy disposal by lagooning, dewatering on sand beds, and direct application to farm lands, golf courses, parks, etc. Digesters also reduce the volume of sludge and in doing so produce gas which can be utilized for heating purposes or gas engine operation.

PROCESS

The digestion process covered in this lecture is that effected in the anaerobic range. Digestion or biological degradation can also be carried in an aerobic state.

The sludge consists essentially of two portions, a solids portion composed of material settled in the clarifiers and a liquid portion containing materials in actual solution. The concentration of material in true solution is relatively low in raw sludge charged to the digester, essentially no higher than contained in sewage entering the treatment plant. These dissolved materials are the only ones capable of affecting the micro organisms.

After sludge is sent to the digestion tanks, the organic materials, contained mostly in the solid portion of the sludge, are slowly hydrolyzed and brought into solution by the bacteria and enzymes present in the digester. Under normal conditions of operation, the organic matter is then quickly broken down into volatile organic acids by a group of bacteria commonly called "acid formers". The organic

acids are in turn decomposed into carbon dioxide and methane by a second group of bacteria commonly called the "methane formers". Because of this decomposition, the quantity of organic matter actually in solution normally remains low. There is, however, a buildup of certain salts in solution such as ammonium, calcium, and magnesium bicarbonates resulting from the breakdown of proteins and soaps. In a digester, these salts produce the natural buffers, which normally remain fairly constant at about 1000 to 3000 mg/1 as calcium carbonate, dependent on the sludge concentration.

When unbalanced digestion conditions exist, the methane-producing organisms cannot remove the volatile acids as quickly as they are formed and consequently a buildup of the volatile acids results in solution. This buildup can take place very rapidly, and in a day or two the total concentration of the materials in solution can be more than doubled. To prevent a disastrous drop in pH from a large acid increase, alkaline material such as lime or sodium hydroxide, may be added for neutralization, the loading rate may be reduced, and dilution water may be added. Above all, the reason for the breakdown must be ascertained and eliminated.

Process failure can be caused by overloading, drastic load changes, temperature changes, and the buildup of toxic concentration of metal ions from industrial waste. The reduction of effective digester volume caused by bottom grit deposits and a scum blanket can also cause a process breakdown.

An average digestion facility being loaded by a domestic waste will reduce the volatile proportion in the sludge approximately 50 percent. This changes the volatile portion from 66 percent to 50 percent of the solids.

DESIGN CRITERIA

General

The capacity requirements for sludge-digestion tanks are primarily dependent upon:

(a) the quantity of sludge that will be treated;

(b) the temperature at which it will be digested;

(c) the volume requirements for concentration, formation of supernatant, and storage of digested sludge;

(d) the extent to which the tank capacity is effectively utilized;

(e) the degree of digestion desired.

With the above five important variables, it is seen that the design problems are many and varied. Past design criteria allowed loadings of two to three pounds of solids per cubic foot per month on digesters heated between 90 and 95°F. Present design criteria allow loading up to and above eight pounds per cubic foot per month. The second figure makes no allowance for dead spaces, scum blankets and bottom deposits, or for shock loadings. The eight pound figure corresponds to a ten day retention period for a five percent (total solids) sludge. It is noted that up to 90 percent of the total gas production can be obtained in the first six days where good mixing is afforded.

Quantity of Sludge

The quantity of raw sludge will depend upon the amount and character of solids in the sewage, the removal of solids by the sewage treatment processes, any change in amount of solids produced by the treatment processes, and the concentration of solids in the sludge to be added to the digestion tanks.

Normally, it is considered that the suspended solids in a domestic sewage averages 0.20 pounds per capita per day. Allowances can be made for industrial waste loadings and garbage grinders.

The removal of suspended solids in the sewage treatment plant varies with the type of sewage treatment and the efficiency of the process as follows:

	Removal Percent
Primary Settling	40 - 60
High-Rate Trickling Filter	75 - 85
Conventional Activated Sludge	85 - 90

The treatment process may increase the amount of solids by conversion of dissolved and colloidal material to settleable solids. Biological processes may reduce the amount of volatile solids by aerobic digestion in trickling filter and activated sludge units.

Since detention period is one of the important factors in the capacity requirements of digestion tanks, the concentration of the sludge solids to be digested requires consideration. This concentration may vary from dense primary sludge at eight to 12 percent solids to dilute excess activated sludge at about 0.5 percent solids. In general, excess activated sludge is concentrated either in separate thickening tanks or, by mixing with raw sewage, in the primary sedimentation tanks. When excess activated sludge is mixed with primary sludge it is difficult to obtain densities exceeding five percent solids. In a small activated sludge plant an average sludge concentration of four percent would be considered good.

Sample Calculations

Example (a) Find required pumping time
Activated sludge process
Consider no gain or loss due to biological activity
Flow 1.0 mgd (1,000,000g)
S.S. concentration in raw sewage 175 ppm
Pump rating 50 gpm
Concentration of sludge 4% (40,000 ppm)

$$\text{Sludge quantity} = \frac{1{,}000{,}000\text{g} \times 175 \text{ ppm} \times 90\%}{40{,}000 \text{ ppm} \times 100}$$

$$= 3930 \text{ gallons}$$

$$\text{Time of pumping} = \frac{3930\text{g/day}}{50\text{g/minutes}} = 78 \text{ minutes/day}$$

Example (b) Find required pumping time
Activated sludge process
Consider no gain or loss due to biological activity
Population equivalent 10,000 persons
Pump rating 50 gpm
Sludge concentration 4%
Sludge quantity =

$$\frac{10{,}000 \text{ persons} \times .2\#/\text{person/day} \times 90\% \times 1{,}000{,}000}{100 \times 10\#/\text{gl} \times 40{,}000 \text{ ppm}} = 4{,}500\text{g}$$

$$\text{Time of pumping} = \frac{4500\text{g/day}}{50\text{g/m}} = 90 \text{ minutes}$$

Temperature

Digestion can be effected in the mesophilic or thermophilic range, 50 to 100°F and 110 to 140°F, respectively. In the colder Canadian Climate, the unheated digested temperature may drop to 45°F where bacterial activity is very low. This being the case, all installations should be equipped with heating devices. Heating may be effected with the outside circulation of sludge through a heat exchanger or by heating coils in the digester itself. The most common temperature maintained in heated digesters is 90 to 95°F.

Ten-State Standards of Digester Sizing

	Cu.ft./Capital	
	Heated	Unheated
Imhoff tanks	--	3 - 4
Primary	2 - 3	4 - 6
Primary + high rate filter	4 - 5	8 -10
Activated Sludge	4 - 6	8 -12

Lower digester temperatures require greater volume allowances in the design.

Sizing of Digesters

In using the imperical loading criteria put forth in the Ten State Standards or the figures of 2 to 3# of solids per cu. ft. per month allowances are made for storage, shock loading capacity, scum blankets, and supernatant separation. The high rate digestion figures must be used with the understanding that allowances must be made for these items.

The ideal digester design will provide complete mixing, by mechanical mixers or gas recirculation in the first stage active digester. When thorough mixing is provided scum blankets are minimized or eliminated, and dead pockets are eliminated. In a second stage unit, the supernatant separation and storage functions are carried out. Even the second stage digester should be equipped with mixing or scum blanket removal facilities. It is noted that only with adequate mixing will the first stage digester capacity be fully utilized.

If carried too far, high rate digestion will transfer the scum blanket problems to the second stage digester.

In smaller installations, the digestion, concentrating, and storage functions must be effected in one tank. This type of installation is difficult to operate and seldom can all the necessary functions be carried out as effectively as desired.

OPERATION

Sludge Pumping

Sludge withdrawn from the sedimentation tanks should be as dense as can be handled satisfactorily through the pumps and piping. Thin sludge occupies digester space needlessly, and its excess water will have to be heated. On heavily loaded digesters, small sludge additions at frequent intervals, assures a uniform digestion rate. On fixed cover units, the loading cycle may have to be timed to correspond to the withdrawn program.

Excepting large plants, where careful control can be maintained over the sludge pumping operation, the piston type pump is to be preferred for digester loading. The centrifugal pump accentuates overpumping. When the sludge becomes thin, the pumping rate greatly increases, whereas the piston unit output remains near constant.

Temperature Control

The most favourable temperature for digestion of sludge from predominately domestic origin is 90 to 95^{o}F. Depending on the digester capacity available, lower temperatures may be used, but some margin of safety should be maintained. Generally, only the first stage digester, in a two stage operation, is heated.

In using internal hot water coils for heating, the water feed temperature should be kept below 130^{o}F. High temperatures will tend to encrust a sludge cake on the coils. Excess water makeup requirements will indicate coil leakage and a smaller than normal temperature drop in the circulation coil water may indicate the formation of an insulation sludge layer on the coils. The use of internal heat exchange coils for digester heating is to be discouraged on all except small installations.

External Heat Exchangers are desirable because of accessibility for maintenance. These units also provide some mixing and at times the raw sludge feed is directed to the recirculation line to be actively mixed with the circulating "seed" sludge. In a system equipped with good internal mixing this step is to some extent redundant.

Circulation and Mixing

The objectives of mixing or recirculation are:

1. Uniform transfer of heat to entire mass.
2. Intimate mixing of raw sludge with seed sludge mass.
3. Prevention of dead areas and scum blankets.

Many systems have been devised for carrying out the above functions. The most satisfactory results are obtained with digester gas recirculation units or internal mechanical mixers. Nevertheless, when these facilities are not available some results are obtained by recriculation using external pumps. Directing the recirculation sludge on top of the scum blanket may assist in controlling its buildup.

In operating mechanical mixers, they can be timed to effect required results. In no case should the timing cycle be set considering power economy alone. In an under loaded digester the mixing units need only be operated to prevent the formation of a scum blanket. The draft tube level may be varied to obtain the best results.

In operating mixers in a single stage digester, the problem of providing adequate scum blanket control along with good solids concentration and also a good supernatant is presented. As there is no absolute answer to this problem, single stage units are to be discouraged. Needless to say, mixing must be discontinued when the supernatant is withdrawn.

Process Control

pH ranges from 6.8 to 7.2 have proved effective in maintaining a good digestion process. Experience has indicated that digester process failure will be far advanced before the pH will indicate the same. The volatile acids test has proved more effective in avoiding a process breakdown. Volatile acid concentrations between 200 and 500 will indicate satisfactory operation. A change from 300 ppm to 500 ppm might indicate a developing problem but until figures 1000 ppm are reached the gas production will remain high.

Recent research indicated that neutralizing compounds can restrict the process, therefore, the actual cause of the rising volatile acids concentrations must be found and corrected. Sodium hydroxide or lime may be used to assist process recovery when the cause of failure has been ascertained.

When the volatile acid concentration is found to be increasing above the normal range, the reason for this rise, insufficient heat, poor mixing, excess space loss due to the bottom deposited grit and scum blanket, toxic, metal ions, or overloading, must be found. Also, as a first step, the loading is reduced or stopped, as required, until corrective measures can be taken. In a two stage operation, the load can be transferred to the second stage digester. In a single stage, one tank, system, raw sludge may have to be removed by tank truck haulage.

In a two stage digestion process transferring may be effected via a connecting equalizing line or by direct pumping or a combination of the two. Occasionally, transferring must be carried out from the bottom withdrawal line or it may become plugged with grit and sand.

Withdrawal of Supernatant

A good supernatant should have a BOD, suspended solids, and volatile acids concentration below 500 ppm. The supernatant is withdrawn to reduce the moisture content of the digested sludge. In two stage units, the separation is effected in the second or cold digester. In single stage units it is difficult if not impossible to meet the above listed quality limits. When the withdrawal system is equipped with multi-level control, the best level must be found and used.

The digester supernatant must be returned to the main treatment process. When the suspended solids carryover is excessive the said process may suffer. Often the supernatant wasting is effected during low flow periods.

Operation Problems

1. Drop of Gas Production

Gas production may be reduced by:

(a) Organic overload causing process failure.
(b) Toxic metals such as copper, nickel, chromium, and zinc may have a toxic effect on the organisms.

(c) Reduced organic loading.
(d) Increasing scum blanket.

A gas production of 15 cubic feet per pound of organic solids destroyed can be expected when effective digestion is taking place. The gas will analyse at 65 to 70% methane and 25 to 30 carbon dioxide. During start up and at process failure, the methane percentage will be greatly reduced. The gas yield from an activated sludge plant can be approximately 1.0 cu. ft. per capita. In an average digestion process, approximately 33 percent of the total solids in the raw sludge are reduced by the process. In more volatile sludges, the percentage will, of course, be higher.

From the above, it is seen that the gas production figures are important in watching the process as a whole.

When the cause of the process failure is ascertained the necessary corrective steps must be taken. The scum blanket elimination would appear to be one of the difficult problems to correct. The installation of proper mixing facilities is the only complete answer to scum blanket control.

2. Foaming

With poor mixing facilities, a heavy scum blanket may form. With heavily loaded units, this blanket may commence to digest, causing a foaming action. This foam may plug gas lines and overflow pipes. A process failure may develop.

The solution is to reduce the load on the digester and thoroughly mix the digester contents to eliminate the scum blanket. At the same time dilution, pH control, etc. may be required to prevent process failure.

CONCLUSION

A few of the pertinent criteria to be used in evaluating a given digestion system have been reviewed. Various operational problems and procedures have been outlined. Anyone interested in further expanding their knowledge on this subject would be advised to consult back issues of the "Water Pollution Control Federation Journal". The Federation Manual of Practice, number 8, also has a thorough outline of design criteria. Much is written on the digestion process so it would be impossible to include a complete reference appendix in this volume.

SLUDGE HANDLING METHODS

J. A. Moore

Assistant District Engineer
Division of Sanitary Engineering

INTRODUCTION

Concentrated sludge and clarifier skimmings collected from the various sewage treatment processes must be disposed of in such a manner so as not to cause health or odour problems. The operation of an otherwise excellent plant is often greatly hindered by economy deletions made in providing equipment for the sludge disposal section of the treatment plant. Nevertheless, when a given plant lacks some of the desired facilities, good operation may in part overcome the presented difficulties.

CLASSIFICATION OF SEWAGE SLUDGE

The following is a definition of sewage sludge:

"Sewage sludge is the accumulated settled solids removed from sewage by sedimentation. Descriptive of its source, it may be termed primary, secondary, excess activated, or chemical. From the state or extent of treatment received it may be called raw, digested, elutriated, dewatered or dried."

The first sentence of the definition indicates that the source of all sewage sludges is sedimentation. However, it must be remembered that there may also be surface skimmings which are obtained by flotation. In the second sentence it is stated that sludge may be called primary, secondary, excess activated, or chemical depending upon its origin or source. Primary sludge is from the first clarifier through which the raw sewage passes. This is one of the first stages of sewage treatment but it may be eliminated at some plants. Secondary sludge is from the sedimentation tank in the secondary or biological section of a plant such as the clarifier after a trickling filter where the coating sloughed off the stones is settled out of the effluent prior to its discharge to the receiving

stream. Excess activated sludge is that portion of the settled sludge being returned to the aeration section of an activated sludge plant which is being wasted and not being returned (the 25 per cent commonly wasted at a lot of plants). Chemical sludge is that which is obtained by chemical treatment of a waste such as in some industrial processes and is not known to most sewage plant operators.

The third sentence of the definition indicates that there are still further names that may be applied to sludge. These are dependent on the state or the extent of treatment that has been given to the sludge. They are as follows:

Raw - this means that the sludge has had no treatment. It is just as it comes from the sedimentation tank.

Digested - the settled raw sludge has been given further biological treatment under controlled conditions in digestion units.

Elutriated - this essentially means that the raw sludge has been "washed" to prepare it for further treatment.

Dewatered - some of the moisture has been removed from the sludge to reduce the volume to be disposed.

Dried - most of the water is removed leaving a relatively dry waste material.

Raw primary sludge being that which is settled out of the raw sewage entering the treatment plant in the primary clarifier, contains bits of garbage, fecal solids, sticks, and other debris. It has a foul odour, is disagreeable in apperance (usually a grey colour), and being highly unstable will readily go septic. The raw secondary sludge is brownish coloured, less odourous and already partially decomposed. Then there is digested sludge which is even further treated and more acceptable in appearance and odour (similar to swampy earth). The digestion process and its resulting sludge will be described in much more detail in other lectures.

Elutriated and dewatered sludges are essentially the same as the above three types of sludge but a portion of the water has been removed and the chemical nature may be changed slightly. Otherwise, the sludges are similar in appearance and odour.

An interesting point about sludges which may be deceiving by their appearance is their moisture content. Depending on the source of the sludge and the nature of the solids in the waste, the moisture content of raw sludge may vary from 90 to 99 per cent of the total weight of the sludge. This means that only 1 to 10 per cent of the sludge is solid material. Therefore, concentration of the sludge or the weight to be handled is proportional to the moisture content. If the moisture content is high, then there is more sludge to pump or truck away.

OBJECTIVES OF SLUDGE TREATMENT

There are three very important reasons for treatment of sludge prior to disposal, which are as follows:

(1) To destory or control sources and agents of disease and infection. Since raw primary sludge is an accumulation of settled waste from a raw sewage, it must be heavily populated with disease causing organisms which could be dangerous to health if it is not properly treated and disposed.

(2) To reduce the volume of material to be handled. The total volume to be disposed of may be reduced by a significant amount if some of the water can be removed.

(3) To reduce odours. Raw sludge is very odourous, and treatment may reduce this.

METHODS OF SLUDGE TREATMENT AND DISPOSAL

The following is a list of the methods of sludge treatment and disposal:

(1) Digestion - biological treatment of sludge under controlled conditions.

(2) Conditioning - elutriation and chemical conditioning (by coagulant aids).

(3) Dewatering - by lagooning, on sand filter drying beds, by vacuum filtration, and centrifuging.

(4) Vacuum filter dewatering followed by heat drying and incineration.

(5) Wet oxidation

(6) Tank truck haulage and disposal on land.

Digestion will not be discussed in this lecture as it will be covered in detail in other lectures throughout the course. A brief description of vacuum filter dewatering will be presented in this lecture to initiate the reader to the process, but it will also be discussed in detail in a future lecture.

Conditioning of sludge will be discussed in conjunction with the processes where it is applicable - particularly in vacuum filtering. It may also be used to prepare sludge for more rapid dewatering on sand filter beds or in a centrifuge.

Sludge Lagooning

Lagoons or waste stabilization ponds are presently very popular as a method of treatment of raw sewage for small municipalities. A similar system is applicable to sludge treatment but it is not common in Ontario. As with the conventional ponds, a sludge lagoon must be located away from buildings because of odours. Even digested sludge has some odour which may not be appreciated at a garden party.

This method of sludge dewatering should be used for digested sludge only. It is not impossible to use a lagoon for raw sludge but it would have to be in a very isolated area because of strong odours and the danger to public health.

The method of operation is simple. Sludge is discharged into the pond daily or as required to remove it from the digester. The moisture in the sludge is removed by decanting, gravity drainage out of the bottom of the sludge into the ground, simple evaporation of water from the sludge, and transpiration (evaporation from plants).

Think of this as a large pond with sludge being added regularly. Some of the water rises to the top and it is allowed to run off through a weir gate. Some water is drained away into the soil below the sludge. A large portion of the water is evaporated into the atmosphere. And finally, some water is absorbed by plants growing on the sludge and some is evaporated from the plants themselves. However, the growth of plants, namely weeds, is to be discouraged.

The design retention time for a conventional waste stabilization pond is 120 days or 1/3 of a year. However, for the sludge lagoons the design retention time, or actually it is the cycling time, is the inverse or three years. It is a long term process and is based on the following time requirements:

1 year to fill the lagoon to a depth anywhere from 2 to 6 feet,

1.5 years to complete the draining of the sludge,

and 0.5 year of resting for the area after the dry sludge is removed.

This seems like a long time but some researchers argue that this is not long enough for drying - this is actually a short cycle they say.

The design factor commonly used is 1 to 1.5 acres for each 1.0 mgd of sewage treatment in a complete secondary sewage treatment plant. More area would be required if it was a small plant with perhaps only one digester. Thus, it may be seem that this method is only suitable for small plants and where land is cheap enough to allow the use of large areas for this method of sludge disposal.

Items to be considered in the design are as follows:

(1) there should be more than one cell because of the long period required after a cell is filled and before it is ready for use again.

(2) to avoid ground water pollution there should be at least 18 inches of soil between the bottom of the pond and the highest point of the water table in the ground.

(3) the surrounding land should be graded away from the pond to prevent surface runoff from entering the pond.

(4) the decanting weir must be opposite the sludge inlet pipe to the lagoon.

(5) the sizing of the cells and the dykes around them. Wide dykes are required if a dragline is to be used for removing the dried sludge. This might not have to be considered if a bulldozer is to be used for this purpose.

The dried sludge removed from a lagoon, especially if the sludge was adequately digested first, is an excellent soil conditioner. It is a black colour and of a fine testure.

It has also been suggested that, in some cases, the lagoon would not be emptied but instead grass could be grown on it and a lawn would result for park use.

In summary, the disadvantages of this method of disposal could be:

(1) land area requirements

(2) odours and nuisance

(3) pollution of ground water

The Research Division of the Ontario Water Resources Commission performed a study in 1964 on the use of lagoons for sludge dewatering. It was concluded that deep lagoons are not effective in producing a dry sludge. However, they are capable of producing a thickened sludge and thus may be economically feasible as a method of reducing sludge disposal costs.

Sand Filter Dewatering

As the name implies, this is a bed of sand which is used to filter the sludge. In this case, only digested sludge can be applied to the bed as it releases its moisture the fastest. Raw sludge contains a large portion of fine material which can quickly clog the bed and also it does not allow the water to separate readily. In addition, oils and greases which are in raw sludge retard the drainage and could quickly plug the sand. The greases are broken up and partially destroyed in a digestor. Also since raw sludge, if applied to a sand bed, would take so long to dewater, that insect attraction and breeding would be likely.

This method of sludge dewatering was very popular in the past for large and small plants. Frequently, the beds were covered by a glass building similar to a greenhouse to keep out rain and to speed drying by evaporation. But today, high labour and land costs now limit the use of this method to smaller plants.

The method of operation of sand filter beds can be described as follows:

> Digested sludge is pumped from a digester onto a bed of sand supported by a bed of gravel with a system of tile underdrains. The dosing is done in one application and the sludge depth is between 8 and 12 inches. After the sludge has dried, it is removed and either used as landfill or a soil conditioner.

The design factors are as follows:

The course sand layer at the top should be 9 to 12 inches in depth and effective size of the sand should be 2 mm.

The supporting gravel layer which contains the open-jointed tile should be 6 to 12 inches in depth above the tile drains.

The walls around the bed should be water tight and extend 15 to 18 inches above the sand and at least 6 inches down into the sand.

The inlet pipe should be at least 12 inches above the bed because the depth of sludge applied may be up to 12 inches.

A splash plate should be provided to prevent erosion of the sand during filling.

The filtrate or water which drains through the tiles should be returned back to the sewage treatment plant processes because it may contain a high 5-day BOD.

The following table gives the approximate area required for exposed and covered sand beds to treat sludges produced in the different sewage treatment processes. The area may have to be increased or decreased for different climatic locations:

Type of Treatment	Area in square feet per capita	
	Open Beds	Covered Beds
Primary	1.00	0.75
Trickling filter	1.50	1.25
Activated sludge	1.75	1.35
Chemical precipitation	2.00	1.50

A solids-liquid separation takes place in the sludge. This is assisted by the gases entrained and dissolved in the digested sludge which tend to buoy up the solids. Thus the

liquid tends to go to the bottom and it is drained off through the sand to the underdrains. A major portion of the water is removed in one day. Then evaporation of the remaining water to the atmosphere is the most important. As seepage and evaporation continue, the sludge cake shrinks horizontally and cracks form in it. This accelerates evaporation as more area of sludge is exposed to the atmosphere.

It has been found that the total drying time to reduce the moisture content to approximately 50 per cent by weight is one to two weeks if the weather is favourable. The volume of sludge may be reduced by up to 60 per cent in this time. Naturally, the drying time depends on the amount of sunshine, rainfall, and relative humidity. A plant in Arizona would have much better drying times than here in Ontario. Also the prevalence and the velocity of winds affect evaporation.

The depth to which the sludge is applied affects the drying time. If the depth is too shallow, it drys quickly, but labour costs rise because there is more frequent cleaning required. If the dosing is too deep then the drying time is toc long and the operator may run out of available bed space. Finally, when the sludge is dewatered to the desired moisture content it can easily be removed with spading forks or flat shovels. In small plants, wooden planks are laid on the bed and a wheel barrow is used to haul the sludge out of the bed area. However, in larger plants other methods have to be devised. These include:

(1) concrete runways for trucks to drive onto the beds,

(2) narrow gauge railway tracks for small dump cars,

(3) monorail buckets which haul to the trucks,

(4) saddlebag bulldozers,

(5) front end loaders and

(6) conveyor belts.

Some sand will be removed with the dried sludge each time that the bed is cleaned. It has been suggested that new sand should be added when the depth of sand has been reduced to one-half of its original depth. In any case, the depth of sand should not be allowed to become too shallow or there will be insufficient depth for filtering. It might also be a good practice to mix the old and new sand to make a uniform size distribution.

To assist in dewatering of the sludge, a coagulant aid may be used. This may decrease the time required for dewatering up to 50 per cent. Alum is frequently used at a dosage rate of 1 pound per 100 gallons of sludge. Lime may also be used but it could increase clogging of the sand bed.

More wet sludge should never be added to a bed of partially dried sludge unless it is an emergency. This would necessitate a much longer drying time for the new sludge as the water would have to drain through the previously applied sludge.

Weeds should not be allowed to grow on the beds. They may be removed by the use of herbicides or through the use of well washed sand.

The sludge draw-off from the digester should be flushed if it does not drain itself to prevent internal pressures of explosive gases produced by digestion in the line.

Vacuum Filter Dewatering

In this case, dewatering of sludge is obtained by a filter with a vacuum applied. Suction is normally thought of when there is a vacuum. This is the principle of operation in this case.

A drum with diameter and length in the range of 5 to 10 feet or more in each direction is rotated on an axle. It is covered with a media of some sort. The drum is emersed in a pan which holds the sludge to be dewatered. A vacuum is

applied on the inside of the drum by a vacuum pump located outside and connected by piping. As the drum turns through the sludge, the vacuum causes water in the sludge to be sucked into the drum and a layer of the sludge solids is drawn onto the outside of the drum.

The vacuum is continued as the drum rotates out of the sludge and into the atmosphere. This pulls more water away from the sludge leaving a moist mat or cake on the outer surface. Just before the portion of the drum being observed enters the pan or vat again the layer of dewatered sludge is scraped, blown, or lifted away from the drum. The dewatered sludge falls onto a conveyor belt or into a hopper. The filtrate water is returned to the sewage plant for treatment again as in the case of the sand filters.

There are various types of filter media which are available. In Ontario, only one type is commonly used. These are as follows:

(1) Fabric covered-includes cotton, wool, felt, dacron, saran, and polyethylene. The synthetics are claimed to have longer life, greater yield in many cases, and the material is more easily cleaned.

(2) String filters - this is a fabric covering but the sludge cake is removed from the drum by strings which pass around the cloth. Thus there is no air blower or scraper required. It is to be noted that the scraper is often called a "doctor".

(3) Coil spring filters - this is the one most commonly used in Ontario. There are two layers of steel coiled springs placed in corduroy fashion around the drum. The spring layers leave the drum, are separated, and the cake is scraped off.

(4) Travelling belt filters - this is a stainless steel woven wire belt around the filter.

The sludge has to be conditioned before it is filtered. This is done in:

(A) elutriation tanks - this is a process often called washing of the sludge. Fresh water or plant effluent is added to the sludge in two or three times the volume of the sludge, they are mixed, settled, and the separated water is returned to the plant for treatment. The primary purpose of this is to change the alkalinity of the sludge.

(B) Coagulation and mixing tanks - conditioning chemicals are added to the sludge which cause the solids to coagulate and thus the water will be released more readily when the sludge is filtered.

These tanks are placed in line before the filter to prepare the sludge before it enters the pan under the filters. The tanks do not have to be large because the conditioning time is short and very critical to the operation of the unit. Also conditioning must be done as a continuous feed.

The speed of rotation of the drum is quite slow - 2.5 to 4 minutes per revolution is usual. The cake thickness on the drum varies between 1/4 and 1/2 inch. The parameter used to specify the rate of filtering is pounds of dry solids per square foot of filter area per hour.

A vacuum filter can reduce the moisture content in a sludge from the 95 per cent range to approximately 75 per cent. This may not seem to be very much, but a look at these figures will show that this is a reduction of about 1/4 of the total weight of the sludge. This is signficant when large volumes of sludge are being treated daily.

Vacuum filters can readily treat raw or digested sludge. They are most commonly used for raw sludge because they remove enough moisture to prepare the sludge for incineration or land disposal.

The factors that the operator of a vacuum filter is most interested in are:

(1) good production yield from the filter,

(2) economy of operation, and

(3) a low moisture content filter cake.

To effectively obtain all these three objectives the operator must try combinations of the following variables:

(1) Dilutions used in elutriation: to obtain the best solids separation and the maximum removal of alkalinity. This in itself can be a complicated trial and error procedure.

(2) Coagulation: too long or too short a conditioning period can reduce the effect of the coagulating chemicals. Mixer speed is also a factor.

(3) Chemical feed: many coagulants and filter aids have been used. Various combinations and feed rates should be tested to obtain the most economical and effective results.

(4) Drum submersion and speed: various drum submersion depths and speeds must be tried. The combination of these factors producing the highest solids yield, along with desirable moisture removal, must be ascertained.

(5) Filter media: the operator might experiment with various filter cloths if economics may allow.

The above operating factors may be summarized in more simple terminology. First, the dilution or the quantity of water added to the elutriation tank can be varied. Secondly,

the type of chemical added, the contact time, and the mixing provided in the coagulation tank can be varied. This is very critical to the process. Thirdly, the drum speed of rotation and its depth into the vat of sludge can have an effect. And finally, one type of media may be more efficient than another.

Proper care and maintenance of the filter are important. The following rules should be followed:

(1) Wash the filter material well with spray jets after every period of use and remove the excess sludge from the pan.

(2) Remove grease with a warm soap solution, if the material is clogged.

(3) Remove lime encrustations with a dilute hydrochloric acid solution.

(4) Adjust the scraper blade properly to prevent wear of the filter material.

(5) Avoid excessive use of chemicals.

As for disposal of the vacuum filter cake, there are several methods available. It can be dried, incinerated, or used as a soil conditioner. However, extended use of the soil conditioner on one area of land may not be advisable as the coagulating chemicals may have an adverse effect on the soil.

One extremely important point to remember is that many plants require duplicate vacuum filter units. Unless there is considerable sludge storage, an operational problem might result when it is necessary to remove the filter from service for routine maintenance or there is an unexpected breakdown.

In comparison to sand filter beds, a vacuum filter requires less area, is independent of the weather, and it can treat raw sludge which eliminates the need for sludge digestion facilities. However, a vacuum filter is more costly to operate.

Centrifuging

Raw sludge may be dewatered to a moisture content of 70 per cent by high speed centrifuging. However, the centrate or the water removed usually contains a high quantity of fine solids. The density of the solids is so close to that of the water that it may stay with the water rather than go off with the heavier solids.

The dewatered sludge may be dried, incinerated or used as a soil conditioner.

Vacuum Filter Dewatering followed by Drying or Incineration

Drying and incineration of the vacuum filter cake are further methods of treatment and disposal. The filtered sludge may be dried to a moisture content of about 10 per cent for use as a soil conditioner or as an additive for commercial fertilizer. If it is desired to dispose of the sludge with the least volume of material to be handled, then it may be incinerated to an inoffensive ash.

These methods must be considered only for very large treatment plants because the costs of installation and operation are very great. Also considerable training and skill is required for the operators.

The purposes for drying sludge are as follows:

(1) to reduce the volume of sludge. There is a considerable reduction when the moisture content is lowered from 75 per cent to 10 per cent.

(2) to retain the fertilizing properties of the sludge.

(3) to retain and improve its soil conditioning properties.

(4) to destroy organisms capable of producing disease

and (5) to reduce odours in the sludge

The purposes for incineration are as follows:

(1) to destroy all organic material.

(2) to kill all organisms.

(3) to control by burning all the gases released

(4) to reduce the volume to a minimum

(5) to produce a readily disposable material by the most economical means of disposal.

Drying of vacuum filter sludge may be performed by the following equipment:

(1) rotary kiln dryers - this is a cylinder which rotates on an inclined axis. The sludge falls down in the cylinder while being mixed with hot (up to 700^{o}F) gases rising in the cylinder.

(2) flash dryers - sludge cake mixed with previously dried sludge is fed to a cage type mill where the sludge particles are dried almost instantly as they are dispersed and held in suspension in a stream of gases at 1100^{o}F.

(3) spray dryers - the sludge is sprayed into a vertical chamber where hot gases mix with it and evaporate the water.

Incinceration is achieved by flash type incinerators, which are similar to the flash dryers mentioned above but the temperature is approximately 1600^{o}F, and multiple-hearth furnaces where the sludge is burned to an ash.

The multiple-hearth furnace consists of a vertical cylinder lined with fire brick and containing a series of four

or more hearths one above the other. Dewatered sludge is fed to the upper hearth and is partially dried by the hot gases from the lower hearths. It is moved successively down to the next lower hearth by rotating plows or mechanical rakes until dried to a point where it will ignite and burn to an ash.

The incinerator has to be equipped with a smoke stack. Therefore, air pollution control facilities have to be included which prevent the discharge of odours, dust, fly ash, and soot.

Dried sludge from the rotary kiln is granular and may contain large clinker-like masses which require grinding for further use. The waste resulting from the flash and spray driers is a fluffy material suitable for fertilizer use.

The ash from sludge incinerators is usually disposed of by using it for fill. Where fill area is available close to the incinerator, the ash can be made into a slurry with water when removed from the ash hopper and pumped to the point of disposal. If the fill area is remote, the ash should be wet sufficiently to suppress the dust and transported by truck or other suitable means.

Design and operation of incineration units is quite complicated. Very few sewage plant operators will become involved in this and therefore these will not be discussed in any more detail in this lecture.

In conclusion, it may be stated that generally landfill, using the filtered cake, would be more desirable than these expensive procedures of drying and incineration, except where the quantity of sludge is very great.

Wet Oxidation

The use of this method is similar to that of drying and incineration in that it is not normally used because it requires expensive equipment and must treat adequate quantities of sludge to justify the construction costs. Successful operation also depends on the maintenace of a continuous supply of homogeneous sludge of fairly uniform solids content.

One argument in its favour is that it can handle either raw or digested sludge. Vacuum filtering is not required first and an 80 to 85 per cent reduction of the BOD of the sludge is achieved.

This is a chemical reaction utilizing high temperature and pressures and oxidation of the organic material in the sludge is achieved by oxidation with oxygen obtained from air. The sludge is reduced to an ash. The liquid portion of the effluent carries the ash which may be removed by sedimentation in tanks or lagoons.

The process, known by the name of its inventor, F. J. Zimmermann, requires extensive high pressure equipment, but the system is self sustaining as far as heat is concerned.

Tank Truck Haulage

Many municipalities are using this method of sludge disposal. It is popular where homes are close to the plant or space is limited for lagoons or sand beds. As long as the distance to the dump site is not too great, it is a simple and economic procedure.

Both raw and digested sludges may be spread on land where adequate aging and cultivation is affected. Where an adequate aging period is not allowed the land should not be used for crops which may be eaten raw. At no time should either raw or digested sludge be spread on growing crops which may be consumed raw. Unless sludges are effectively heat dried they should not be spread on active grazing land. Forage crops which have been treated with sludges not rendered innocuous by heat drying should be cured before use.

With the exception of the nitrogen and phosphorous content in undigested activated sludge, the fertilizer content in sludge is small. Therefore, the greatest percentage of sludge products are classified as soil conditioners, and not fertilizers. Nevertheless, this material, whether termed as fertilizer or soil conditioner, can provide valuable humus and trace elements to the soil. The three main constituents required in commercial fertilizer are nitrogen, phosphorous and potassium. Nitrogen and phosphorous are available in good percentage in sewage sludge while potassium is generally available in amounts less than 1 per cent.

The type of treatment from which the sludge originates, as well as the nature of the raw sewage, have a great bearing on the value of the resultant sludge as a soil conditioner. In the order of value with respect to nitrogen content, undigested activated sludge is greatest with digested activated sludge, raw primary sludge, and digested primary sludge following in that order.

In purchasing a vehicle, the quantity of sludge to be removed must be known as well as the length of haul, the time an operator is available, and other uses for which the truck may be used. For small plants, finances will greatly limit the type of vehicle which may be obtained.

Sludge tanks which will be utilized for liquid sludge transportation should be constructed with an oval or round cross-section. Structual cracks will develop in the thin plate if a square design is followed. The use of twelve gauge high tensile steel plate will provide corrosion resistance and more than adequate strength. The use of a top operated valve, with the valve located in the tank itself, for the sludge discharge line will prevent freezing during winter operation. When a four inch gate valve is used, the pipe between the tank and the valve itself must be insulated and also provided with a heating element. The tank must also be constructed with adequate internal baffles, inspection and loading manholes, and vacuum relief valves on the top.

Sludge cake should, if possible, be handled in a dump box equipped with a water tight gasket on the rear gate. The sides should have more than normal freeboard allowing one cubic yard of volume for each ton of cake to be carried. A heavy duty hoist is advised to enable spreading with the box up while travelling over rough terrain.

When disposing of sludge great care must be taken to ensure that nuisances are not created. Common sense rules must be followed to prevent obnoxious odour complaints. When a municipality receives numerous complaints regarding refuse and sludge disposal, very restrictive regulations may be enacted.

Only very isolated dumping areas should be used for raw sludge and the applied material must be plowed in very quickly. Winter weather will prevent odours but it may be

difficult to work the sludge into the soil early in the spring and obnoxious odours might develop at that time. In general, raw sludge products must be very carefully handled. It might be advisable to dispose of raw sludge at a land fill project, where daily coverage can be provided.

Digested sludge is less odourous and therefore immediate coverage is not as important. Liquid sludge can be spread evenly and thinly. Where quick drying is possible, on sandy and elevated dry land, it may be disposed of close to homes. Nevertheless, great care must be taken that obnoxious odours do not carry to residences and furthermore, only well digested liquid sludge can be considered in this category.

Digested sludge cake must be handled more carefully. It is difficult to spread thin and therefore wet lumps of material may emit some offensive odours. If possible this material should be worked into the soil soon after spreading.

CONCLUSIONS

In most of the methods discussed in this lecture, a point that should be noted is the per cent of moisture removed. A decrease of 10 per cent may seem to be a very small amount for the quantity of work and time involved. But over a period of years of handling large volumes of sludge, this may make a tremendous difference in the total volume handled. Consider the cost of a trickling filter system in comparison to a tank truck. Initially the truck is much cheaper, but after a few years of problems in hauling during the winter season and summer cropping times combined with long haulage distances, the filter may be much cheaper in the end.

A study performed in England produced the following conclusions:

(1) It is desirable to thicken the sludge prior to sand bed drying because there is less water to be removed and therefore, an accompanying decreased drying time is required.

(2) Vacuum filtration and heat drying are independent of weather conditions. However, they require considerable labour and are very expensive.

(3) Tank truck disposal is final and cheap. But a moderate labour force is required which is significant in the holiday season.

(4) Drying beds fall midway between other methods in total cost and labour requirements are low. However, disposal of the dried sludge could be difficult and the large area required is their greatest disadvantage.

CHLORINATION OF SEWAGE

M. B. Fielding
Supervisor, Applied Sciences
Division of Research

Chlorine is one of the commonest chemicals used in sewage treatment plants. In the following text the various uses to which it may be put will be discussed but before that a general description of the material itself is warranted.

The first point which must be stressed is that chlorine, particularly in its gaseous state is dangerous. This will undoubtedly be impressed upon you in your discussions of safety practices.

Chlorine (chemical symbol Cl_2) when added to water forms free chlorine ion (Cl^-) and acid.

It may be added as gaseous chlorine (Cl_2) or as hypochlorite ($Ca(OCl)_2$).

In either form the results are similar - the release of a strong oxidizing agent which will produce the following results.

DISINFECTION

The most important use of chlorine is for the disinfection of plant effluents. This is essential to protect water supplies and recreational areas in the vicinity of the sewage treatment plant. The amount of chlorine necessary to obtain a satisfactory reduction of bacteria will vary greatly with the kind of treatment the sewage has received. While the effluent from a well operated activated sludge plant or trickling filter may require only 2 - 3 ppm, a primary sedimentation plant, where prechlorination is necessary in order to obtain adequate contact time, may require a dosage of 40 ppm or more of chlorine. It is not practical in any case to specify a fixed dosage for chlorine but rather to require sufficient chlorine to give a specific

chlorine residual after an adequate contact time, e.g. a chlorine residual of 0.5 ppm after 15 minutes contact has been found adequate in most cases.

ODOUR CONTROL

Odours in sewage treatment plants that are due to an anaerobic condition will usually respond to chlorination. In most cases the problem is to find the best point of application for the chlorine. In the case of primary clarifiers where the sewage has become anaerobic during the sedimentation period, the chlorine should be added to the incoming sewage. When the odour develops in the sewers due to a low velocity, the chlorine should be added far enough up the sewer so that it has adequate time to control the anaerobic condition before the sewage leaves the sewer.

Industrial wastes with high oxygen demand such as come from packing houses, canneries, milk plants, etc. will turn anaerobic very rapidly and if this type of waste is found to be causing odour it should be chlorinated before it enters the sewer.

In controlling odours it is not necessary to chlorinate to a residual. It has been found that a dosage of 40 - 60 per cent of the chlorine demand will give satisfactory control.

BREAKDOWN OF CONCRETE AND MORTAR

The hydrogen sulphide that develops in anaerobic sewage can cause other problems besides odour. This gas is quite soluble in water and will dissolve in moisture that has condensed on the walls and roof of a sewer. It is then oxidized by the air and the sewer to sulphuric acid and will dissolve the cement from the concrete and mortar and allow them to crumble. Chlorine, of course, is the answer to this problem, as it will oxidize the hydrogen sulphide before it condensed on the surface of the concrete and will also control the organisms that produce the gas.

AID TO SEDIMENTATION

Chlorination of raw sewage will improve the rate of settling in primary clarifiers. This is especially true when the sewage is anaerobic as it destroys the gas forming organisms and prevents the sludge from rising.

BOD REMOVAL

Chlorine reduces the BOD of sewage in two ways. Some of the decomposable matter is oxidized by the chlorine resulting in a permanent BOD removal, other compounds combine with the chlorine to form chloro compounds some of which are toxic to bacteria and others are no longer broken down by bacteria. The BOD reduction will vary from 15 - 35 per cent depending on the condition of the sewage. Generally speaking the lowest reduction is obtained in fresh sewage and the highest in anaerobic sewage. A BOD reduction of 2 ppm for 1 ppm of chlorine is obtained up to the point where a chlorine residual is obtained. Beyond this point the rate of oxidation drops off.

GREASE REMOVAL

Chlorination can be used ahead of a clarifier as an aid in grease removal. The chlorine will break the grease emulsions allowing the grease to collect in larger particles that are easier to remove by skimming.

ACTIVATED SLUDGE

There are a number of ways that chlorine can be used to advantage in operating activate sludge plants. In some cases sludge bulking can be controlled by chlorinating the return sludge. This will require about 5 ppm of chlorine and should be continued until a satisfactory sludge index is obtained. Sometimes at the start of this treatment the effluent becomes quite turbid but this condition should clear within a day.

When waste sludge that is being returned to the primary clarifier tends to float, chlorination of this sludge will give better settling.

When an activated sludge plant is overloaded there are several points in the plant where chlorine can be added to reduce the load. It can be used ahead of the primary clarifier to reduce BOD and increase the amount of solids settled, or it can be added to the aeration channels to aid in oxidation, or then added to the final clarifier, it can be used to control biological activity and prevent floatation of the sludge. The best point to add the chlorine can only be determined by experience and varies from plant to plant.

When a plant has become anaerobic from breakdown or overloading, chlorination is the quickest way to return it to an aerobic condition. In this case, chloride of lime is more effective than chlorine gas, as the pH is always low when a plant is anaerobic, and the lime raises the pH while the chlorine corrects the anaerobic condition. Care should be taken that the pH is not raised to the point where calcium carbonate is precipitated as it tends to form scale on the diffusers and plug them.

Supernatant liquor from digesters also introduces a problem in activated sludge plants that can be relieved by chlorination. Due to the high chlorine demand of this liquor, dosages as high as 80 ppm or more may be necessary to give adequate control.

Some success has also been attained in cleaning air diffusers by feeding chlorine gas into the diffuser headers.

TRICKLING FILTERS

Several methods of chlorination have been used to clear up ponding of trickling filters. It has been found that dry calcium hypochlorite sprinkled on the surface, or a solution of hypochlorite sprayed on the surface, will cause the slime growth that is causing the ponding to slough off. Another method is to feed chlorine to the sewage going to the filters until the slime growth is cleared. In this case, the

recommended chlorine residual in the sewage going to the filter varies from 1 - 10 ppm. Where ponding is a frequent problem it may be necessary to set up a programme of chlorination at regular intervals. In some cases chlorination as often as one night each week has been used.

Where slime growth has penetrated deep into the filter more drastic methods may be necessary, such as flooding the filter with a strong chlorine solution. This will result in the removal of all biological growth from the filter and a period of 5 - 6 weeks will be necessary to bring the filter back into good operating condition.

Filter flies can be controlled by chlorination but it does not eliminate them completely. The recommended dosage varies from 3 - 10 ppm.

Chlorine can also be used to control the odour that is characteristic of trickling filter plants.

Chlorination of trickling filters is usually carried out at night when the chlorine demand of the sewage is at its lowest. This results in a considerable saving in the amount of chlorine used.

SLUDGE THICKENING

In some plants, sludges, both activated or primary, are thickened before they are pumped to the digester or dewatered. Chlorine can be used here to control bacterial action and better settling and concentration is obtained. To do this it is necessary to maintain a residual of 1 ppm of chlorine in the supernatant liquor above the sludge.

STREAM PUTREFACTION

Chlorine can be useful in controlling putrefaction in a receiving stream. As stated earlier it is possible to obtain a BOD reduction as high as 35 per cent and also the chlorine slows up biological action, so that in some cases it is possible to carry the load to a point where there is

adequate dilution to take care of it. However, chlorination is not always an answer and on some small streams it just moves the nuisance area to a point further downstream.

CONTROL OF CHLORINATION

Due to the great variation in flow and strength of sewage, an accurate control of chlorine residual is impossible. In small plants it is suggested that the residual be checked each day at the time when it is known the maximum load is being received. This will assure of always having sufficient chlorine. In larger plants it will be worthwhile to adjust the dosage during the night when the flow and chlorine demand is much lighter. In very large plants automatic or semi-automatic chlorinators will be used and it is possible that dosage will be checked as often as every hour.

TESTING FOR CHLORINE RESIDUAL

There are three methods used in testing for chlorine residual:

(1) ortho tolidine
(2) starch iodide
(3) amperometric

The ortho tolidine test is much the simplest but unfortunately there is too much interference in some sewages and a test cannot be made. In smaller plants we would recommend that the ortho tolidine test be used if it will give satisfactory results.

MAINTENANCE IN SEWAGE TREATMENT PLANTS

B. M. Hines,

Chief of Regional Maintenance

MAINTENANCE SCHEDULES IN SEWAGE TREATMENT PLANTS

Equipment maintenance is one of the keys to efficient operation of a treatment plant. The equipment that is designed or selected with extreme care by the Consulting Engineer or your engineering department, purchased under detailed specifications and operated by qualified men will not be efficient for long unless it is cared for. Such care is normally of two types:-

1. Breakdown maintenance and

2. Preventive maintenance.

Breakdown maintenance is the repair of equipment after failure and is usually of an emergency nature. Preventive maintenance, on the other hand is planned or scheduled maintenance of the "fix it before it breaks" type, and is designed to eliminate or minimize breakdown maintenance.

The value of eliminating or nearly eliminating breakdown maintenance in the treatment plant can be easily appreciated. If treatment is to be continuous, the treatment plant cannot let its major pieces of machinery run until they fail and then repair them unless it is supplied with an over abundance of standby equipment. As you all know, equipment has an uncanny and unfortunate habit of breaking down when it is needed most or when it is most awkward or difficult to repair.

Preventive maintenance, which by definition is scheduled and planned maintenance is an alternative to an over abundance of standby equipment. It is not now, nor has it ever been economically feasible to provide 100% or more standby for all equipment required on peak flow days. Thus, by providing for the repair and servicing of equipment at periods of the year when service to the public is not so critical as at other times, scheduled maintenance can provide a reasonable assurance that breakdowns will not occur when the equipment is needed.

I am not saying that all breakdown maintenance can be completely eliminated. A reasonable objective is that of spending not more than 20% of the man-hours of equipment maintenance on breakdown maintenance. With some types of equipment, such as centrifugal pumps, breakdown maintenance can be almost completely eliminated if scheduled preventive maintenance is adequate.

To bring breakdown maintenance to a reasonable level, it is necessary to give your maintenance policy the same careful attention that is usually given to the operation of equipment.

Basic Features Of a Sound Maintenance Policy

1. Responsibility for maintenance must be clearly defined and in the hands of competent personnel.

2. A thorough knowledge of the equipment.

3. Proper tools, spare parts, test instruments and shop facilities for maintenance.

4. Preventive action must be planned and scheduled.

5. An adequate system of written records and reports must be used to permit control over the program.

The need for maintenance is something that usually does not show, therefore, it is important to make clear and definite assignment of responsibility. When maintenance is everybody's business, equipment breakdown becomes nobody's fault. An assignment of responsibility for maintenance should usually be made to one person who has the capacity, aptitude and is allowed time for the job. The person should be given the help he needs as indicated by the type, amount of maintenance work required and the size of the operation.

The fact that the maintenance personnel must be qualified and experienced in maintenance work cannot be over emphasized. Knowledge of such important maintenance factors as what constitutes excessive vibration? When bearings should be replaced? When welding constitutes a safe repair? What a loose fit is? These and similar points, are only acquired by experience, training and education.

The knowledge of your equipment can be obtained from the instruction manuals issued by the manufacturers of the equipment. These manuals, as distributed to you, are a result of many years accumulated experience on the part of the manufacturer. Experience gathered from all types of equipment application and tests both in the field and on the shop floor, and under all operating conditions.

An adequate supply of properly sized common shop tools are needed for efficient maintenance procedures. These tools should be of the best quality available. Cheap tools cannot only damage equipment but will be more costly in the long run and create safety hazards.

Special tools for certain units should be well cared for. The tools a mechanic uses and their condition is a good indication of the calibre of the mechanic. Repair parts should be stocked according to the number of machines or equipment installed and the expected life of the equipment parts. The manufacturer can give you helpful suggestions on this. Also consideration should be given in the purchasing of spare parts as to the priority alloted to the individual piece of equipment. The priority rating is established by asking the following questions:-

1. Is this piece of equipment vital to process or production?

2. What down time can be tolerated?

It will be found that your maintenance management problems will require less decision making if the priorities of maintenance are pre-planned. To maintain all capital equipment to the same degree will usually produce one of two results, either the maintenance cost will be extremely high or the equipment will be poorly maintained causing breakdown.

For this reason equipments are usually divided into three priority groupings and the maintenance dollars spent to best advantage. The groupings are as follows:-

Priority 1 -The equipment that is vital to process and without such equipment a process cannot be achieved.

Priority 2 -The equipment, considered as standby equipment, could be considered as reliable over shorter periods of time.

Priority 3 -That equipment, not vital to process which serves a function other than process. W.P.C.P. plants are usually designed for future flow increases therefore the numbers of pieces of equipment in the number one priority should be relative to the flow.

The establishment of maintenance and inspection of a regularly scheduled basis is the initial step in setting up a preventive maintenance program which will assure continuity of the operation. Preventive maintenance refers to inspections and equipment care performed routinely according to the requirements of the equipment. For example preventive maintenance schedules mean keeping equipment clean, in a state of good order and proper operation, free of excessive vibration,properly lubricated, and free of overloads and improper heating. Preventive maintenance requires a periodic check for wear and then the replacement or repair of parts before breakdown occurs. Such inspections often require the complete disassembling and reassembling of the equipment on a routine scheduled basis.

Preventive maintenance is successfully practiced when it is properly planned and performed according to a prearranged schedule. It requires the same attention and should be given the same importance as the transfer of sludge, holding digester temperatures or the cleaning of bar screens. Unless preventive maintenance is routinely performed and regarded as much a routine requirement of plant operation as are other plant operations, breakdown maintenance cannot be avoided.

If for example, experience indicated it is desirable to blow out an electric motor on a chemical conveyor at least once a week, then this clean up operation must be performed routinely, without miss, if the performance life of the motor is to be preserved. To miss a week is to invite a second miss and third, until breakdown finally tells you in a forcible, expensive way, how long a dirty motor will operate.

Again, if a manufacturer has recommended the lubrication of a bearing every three months, with a particular grade oil or grease, experience has usually confirmed the reasonableness of this recommendation. Good judgement dictates that this lubrication should be scheduled routinely as recommended and not just when the operator happens to remember to do it, or with whatever lubricant is at hand.

To say that, unless a treatment plant follows a scheduled maintenance program, breakdowns and interruptions in service are inevitable may seem to be stretching the truth. But it can be said without any reservations that, unless preventive maintenance is scheduled and routinely performed on time, there is no assurance that such breakdowns will not occur. In other words, I am not prepared to gamble that if you have a scheduled maintenance program, you won't have breakdown, but I will give you odds that you will have breakdowns without scheduled maintenance.

The planning of a preventive maintenance program therefore, requires that equipment items be studied to determine the maintenance operations required and the frequency of these operations. This is determined from an analysis of service conditions of the equipment, from your operating experiences, from the operating experiences of others and from equipment manufacturers recommendations.

Each equipment item or unit must be studied individually, for even similar pieces of equipment may have different care requirements because of location or service.

To carry out and administer a maintenance program effectively requires a minimum or records and forms, yet such records are very important to successful maintenance. The importance of records and reports have been dealt with elsewhere in basic sewage operators course and will not be expanded upon at this time, but suffice to add that firstly the planned and scheduled portion of maintenance must be tabulated and calendered.

Preventive maintenance operations are too numerous, even in the smallest plant, to depend upon the memory of one or more individuals. Such a practice is just as ill advised as depending on one or two old timers to remember where some of your manholes are located after they have been covered over by the roads superintendent with three inches of black top. Then, too, maintenance planning is apt to be more thorough when the scheduling is stated in writing.

Preventive maintenance records are also necessary to note when preventive maintenance operations were last performed,who was the maintenance mechanic, and what work was done.

Finally, a record of the extent of unscheduled or breakdown maintenance is also necessary. An analysis of these and their causes may indicate that they could be prevented if scheduled maintenance had been performed.

From the standpoint of preventive maintenance and in the attempt to eliminate, or partially eliminate breakdown it is equally important to be aware of that which has not been performed, as that which has been performed.

The record requirements can usually be conveniently accomplished with not more than two forms, - - one for preventive maintenance and the other for unscheduled or breakdown maintenance.

In the Commission, our Chief of Maintenance has developed a set of preventive maintenance forms, the use of which has been standardized throughout all our projects either water or sewage treatment and applies to either large or small projects. They can be called "work reminders" or "scheduled preventive maintenance forms." The purpose of the preventive maintenance forms are:-

1. To list how often and when what work is to be done.

2. To list the preventive maintenance work required on each piece of equipment.

3. To report preventive maintenance operations when completed, or not completed.

With these simple forms a very complete preventive maintenance program can be administered.

In summary, where continuity of service and performance is of prime importance, as is in a sewage treatment plant, good maintenance is good management and good operation and good maintenance is scheduled preventive maintenance that will cut breakdowns and unplanned equipment outages to a minimum, as well as keeping equipment operating at peak efficiency. No treatment plant is too small to install or institute a preventive maintenance program, and no community is rich enough to be able to afford not to take care of its equipment and get the most out of it.

Remember that you are not operating a plant that is handling a profit making project, you are only providing a service. A sewage treatment plant does not pay its own way and is a constant drain on the community's resources. It is therefore necessary for you to operate your plant as efficiently and as economically as is humanly possible and to use every know method of doing so.

FLOW MEASUREMENT AND SAMPLING ROUTINE

A. C. Beattie
Regional Supervisor
Division of Plant Operations

FLOW MEASUREMENTS

Quantity is an amount of something. In the case of fluids (liquids and gases), quantity is a measure of either volume or weight of a substance contained in a tank or pipe, etc.

Measurement of Quantity

Quantity of a liquid may be determined by weighing it in standard units such as (pounds, kilograms, or parts thereof) or by measuring the volume occupied using standard units such as (cubic feet, gallons, liters, etc.).

Quantity of a gas is preferably determined by measuring the volume occupied in terms of cubic feet, liters, etc.

Quantity of both liquids and gases will vary with both temperature and pressure changes. Therefore, it is necessary to set standard conditions to which measurements of quantity can be referred for comparison.

Pressure effects on liquid are negligible; therefore, the standard condition for liquid measurement is 60°F. Both pressure and temperature are important in gas measurement; the standard conditions are 60°F. and 30 in. of barometric pressure. Laboratory observations are sometimes referred to 0°C. (32°F.) and 760 mm (30 in.) pressure.

Concept of Flow

"Flow" is quantity in movement from one point to another (or past a point) in a specified interval of time. This fundamental idea of flow may be visualized from Figure 1, which shows a pipe connecting two tanks containing a liquid. When the valve is closed, there is no movement of liquid from one tank to the other. Under these conditions the volume of the liquid in the pipe is represented by:

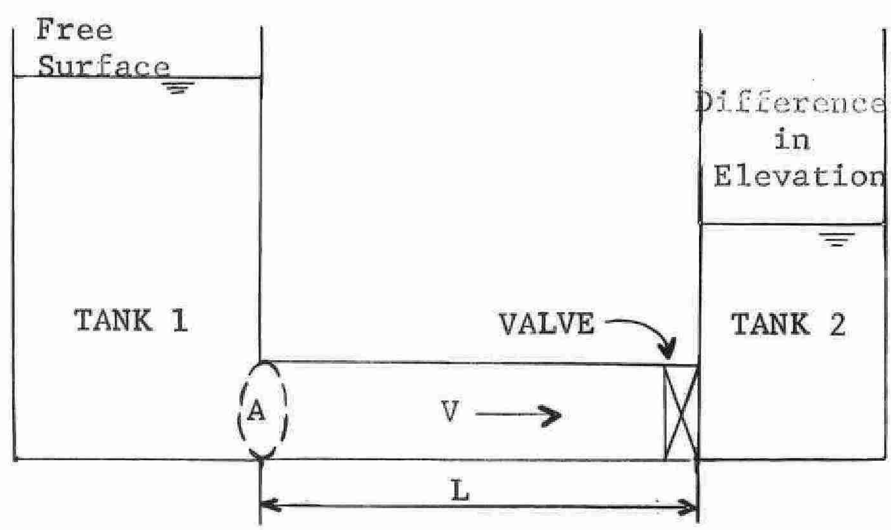
$$V = A L \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

in which: V - is the volume
A - is the cross-sectional area, and
L - is the length of the pipe.

Figure 1 - Fundamental Concept of Flow

If the valve is opened, the liquid moves because it is under pressure (head) since the liquid in Tank 1 is higher than the liquid in Tank 2. The quantity moving then becomes the number of times that the length of pipe, L is filled and emptied in a given period of time, T.

FIGURE 1



Since L/T = Velocity, it is obvious that for flowing liquids:

Q = Volume, in cubic feet per unit time, T;
A = Area, in square feet; and
V = Velocity in feet per unit time, T
(usually per second or per minute).

The term "rate of flow" is applied to measurements of quantity in motion for a relatively short unit period of time; for example, per second, minute, or hour and sometimes day. "Total flow" or volume, is the term applied to the total amount of liquid moved during any unit of time, usually referring to a period of a day, month or year, (rate of flow is volume per unit time; total volume is average rate multiplied by the time the flow exists). Rates of flow of liquids are usually expressed in one of these units.

Cubic feet per second (cfs) (or per minute, per hour,etc.);
Gallons per minute (gpm)(or per hour, per day, etc.);
Million gallons per day (mgd);
Pounds per minute (lb. per min.)(or per hour, per day, etc.)

Total volume is expressed in cubic feet, gallons, million gallons, usually per day. Rate of flow for gases is usually expressed in cubic feet per minute (cfm) or per hour, per day, etc. referred to standard conditions.

COMMON CONVERSION FACTORS

Parts per million (ppm) is always by weight. In the sanitary field ppm represents the number of pounds of dry solids contained in one million pounds of water.

1 ppm = 10 pounds per 1,000,000 gallons.
1 pound per 100,000 gallons.

1 Imperial gallon	=	1.2 U.S. gallons
1 Imperial gallon	=	4.54 liters
1 U.S. gallon	=	8.35 pounds of water
1 cubic foot	=	6.24 Imperial gallons
1 cubic foot	=	1,728 cubic inches
1 cubic foot	=	28.32 liters
1 cubic yard	=	27 cubic feet

1 foot	=	30.48 centimeters
1 centimeter	=	0.3937 inches

Atmospheric pressure	=	29.92 inches of mercury
	=	33.9 feet of water
	=	14.7 lbs. per square inch

1 Grain per U.S. gallon	=	17.12 ppm
1 Grain per Imperial gallon	=	14.25 ppm

Grams per liter = 1,000 ppm

1 kilogram = 2.025 pounds

REASONS FOR FLOW MEASUREMENT

In any sewage treatment works there are a number of reasons for measuring flow, as follows:

1. To provide data and information on plant operations. Data on total volume treated in a plant, or handled in sewers, in a day, week, or year, will serve for comparison purposes and help to chart trends and conditions necessary for future planning and changes or additions needed in the system.

2. Data on rate of operation and total volume handled by individual operating units, aid in the proper operation and maintenance of those units; for example, settling tanks, trickling filters, activated sludge units, digestion tanks, etc.

3. To provide information on operating efficiency, particularly unit operations, such as pumping, sedimentation, oxidation disinfection, and digestion.

4. To ascertain quantity of sewage received from outlying communities or from industrial establishments, particularly where charges for treatment are made against outlying community or industries.

5. To determine costs of operation, both overall and unit operations, since practically all costs are based on volume handled, usually calculated per million gallons.

6. To provide records of performance. Such records enable officials responsible for plant operation to prepare reports to the public and to governmental health departments on accomplishments of the plant and efficiency of operation. Records are also an aid in the case of lawsuits resulting from alleged pollution or nuisance conditions.

MEASUREMENT OF FLOW

There are many methods and devices available for measuring flow but only a few of the more common ones will be discussed in this lecture.

MEASUREMENT BY WEIGHT

A scale can determine the weight of fluid confined in relatively small containers, and thus give a measure of total quantity; but it is generally impractical to weigh large quantities and such a system can be applied only to batch measurements.

Measurement of flow rates of liquids on scales is possible only in loss-of-weight feeders or meters, which continually weigh, indicate, and record the decrease in weight of a container of liquid. Tank car lots are the largest feasible size of container for this purpose. Chlorine is measured on a loss of weight basis, i.e., pounds per day.

FILL AND DRAW MEASUREMENT

The total quantity of a liquid can be determined if the liquid enters and leaves a vessel of known volume. This method has the limitations that the change in level must be due solely to the liquid entering or leaving the

tank; input and output must not take place at the same time.

The fill and draw concept is useful for measuring flows in and out of sedimentation tanks, digestion tanks, etc. Rate of flow can be determined by timing the linear travel of the surface of the liquid.

For example:

Suppose you had a digester with a diameter of 60 feet. The liquid in one inch of this digester would be

$$A = \frac{\pi}{4} d^2 \quad \text{or} \quad \pi r^2 \text{ X depth}$$

Volume = A x depth

$$3.14 \times \frac{60 \times 60}{4} \times \frac{1}{12} = 236 \text{ cubic feet}$$

Since 1 cubic foot = 6.24 gallons then

1 inch of digester holds 6.24 x 236 = 1,470 gallons

Now if you had a centrifugal pump that raised the liquid level four inches in 9 minutes it would have a capacity of:

$$\frac{4 \times 1470}{9} = 654 \text{ gallons per minute}$$

This illustration is not always practical in actually determining flow rate for the following reasons:

1. It may be physically impossible to alter the liquid level in the digester so quickly.

2. From a biological point of view, there would be a chance of the digester being upset.

3. The discharge of the pumps will be greatly altered with different liquid levels in the digester.

4. When a small change in liquid level takes place, there is a great possibility for error in measuring the change in liquid level. For instance, if you raise the level only 2 inches and your measurement was 1/4 inch out, the error would be 1/8 or 12½ per cent.

This type of flow measurement is very easily done when a new unit is added to a plant. For instance, if a new digester is pumped full or water or sewage, there is a great opportunity for finding out the discharge characteristics of your pumps and pipes with various head conditions.

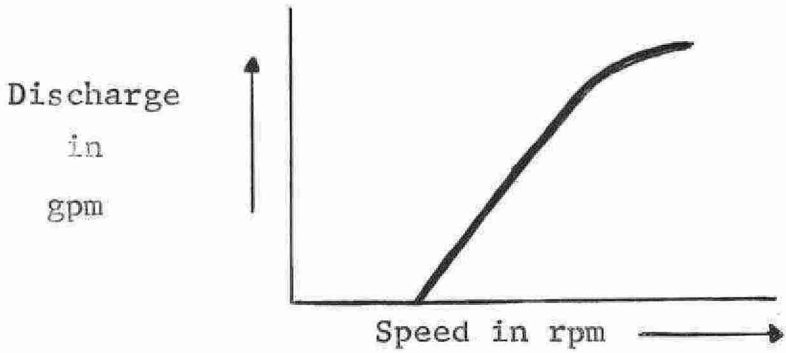
Another example of similar testing would be in clarifiers or aeration tanks where you could shut off all incoming flow and then measure the drop in water level at various pump speeds.

All this information is extremely useful to a plant operator in controlling his plant and maintaining his records. Incorrect pumping to digesters or returning sludge could offset any calculations which may have been made. If incorrect data is recorded at the plant, it may give misleading results and it really makes the keeping of records a waste of time.

Pumps

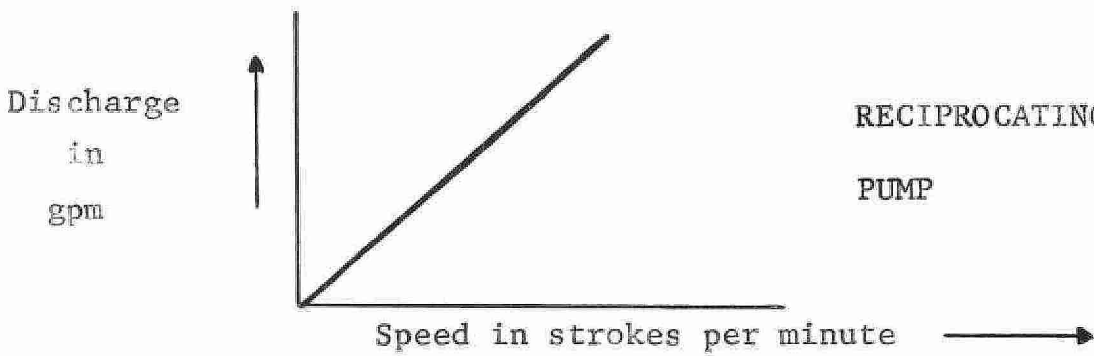
If liquids are pumped, the number of repeat cycles of operation of the pump can be used as a measure of the total flow and the rate of these operations can be used as a measure of rate of flow.

Controlled volume reciprocating pumps give a constant output for each cycle of operation against any head; but centrifugal pumps, if used for measuring purposes, must be calibrated as to discharge for each speed of operation, suction lift and discharge pressure.



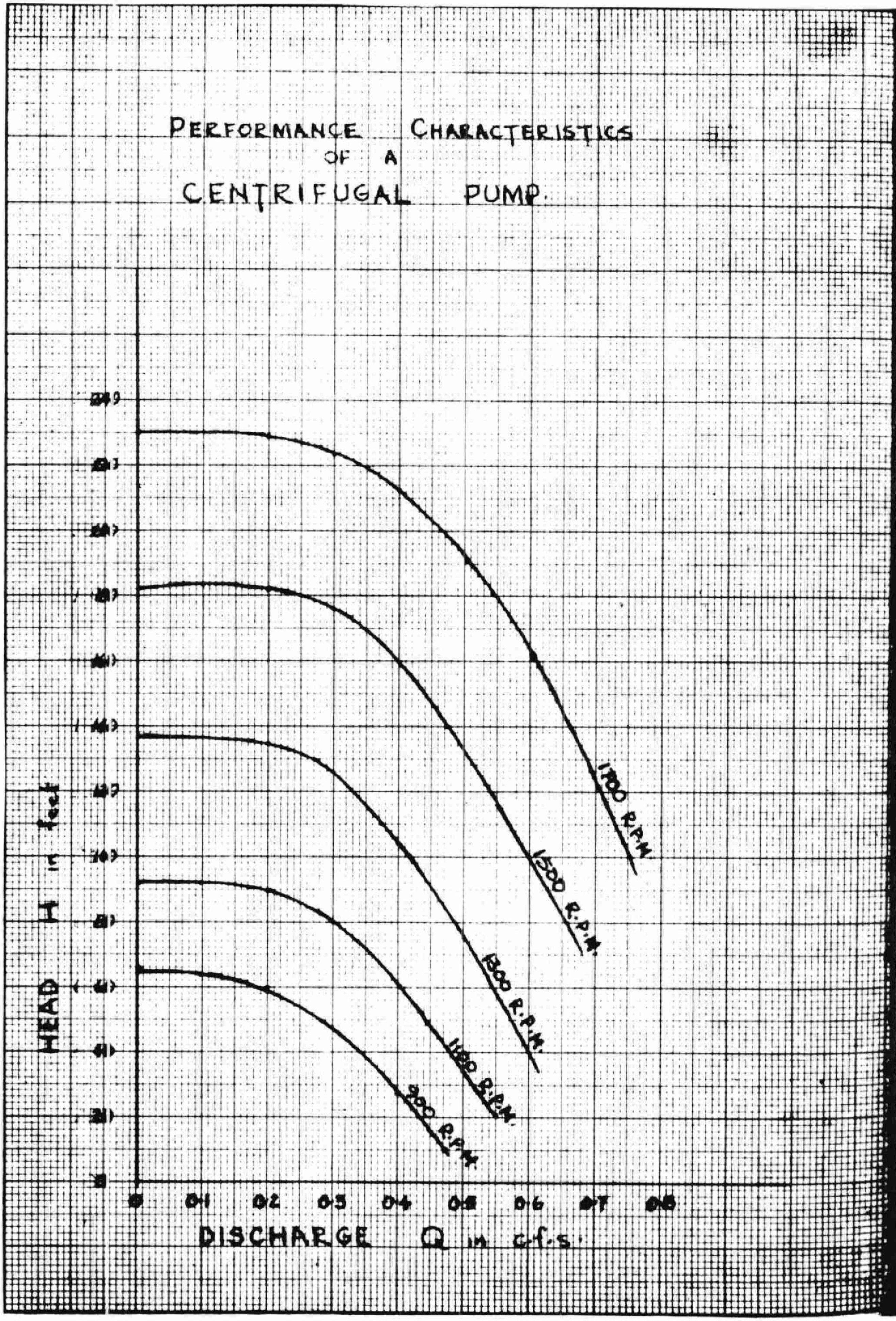
CENTRIFUGAL

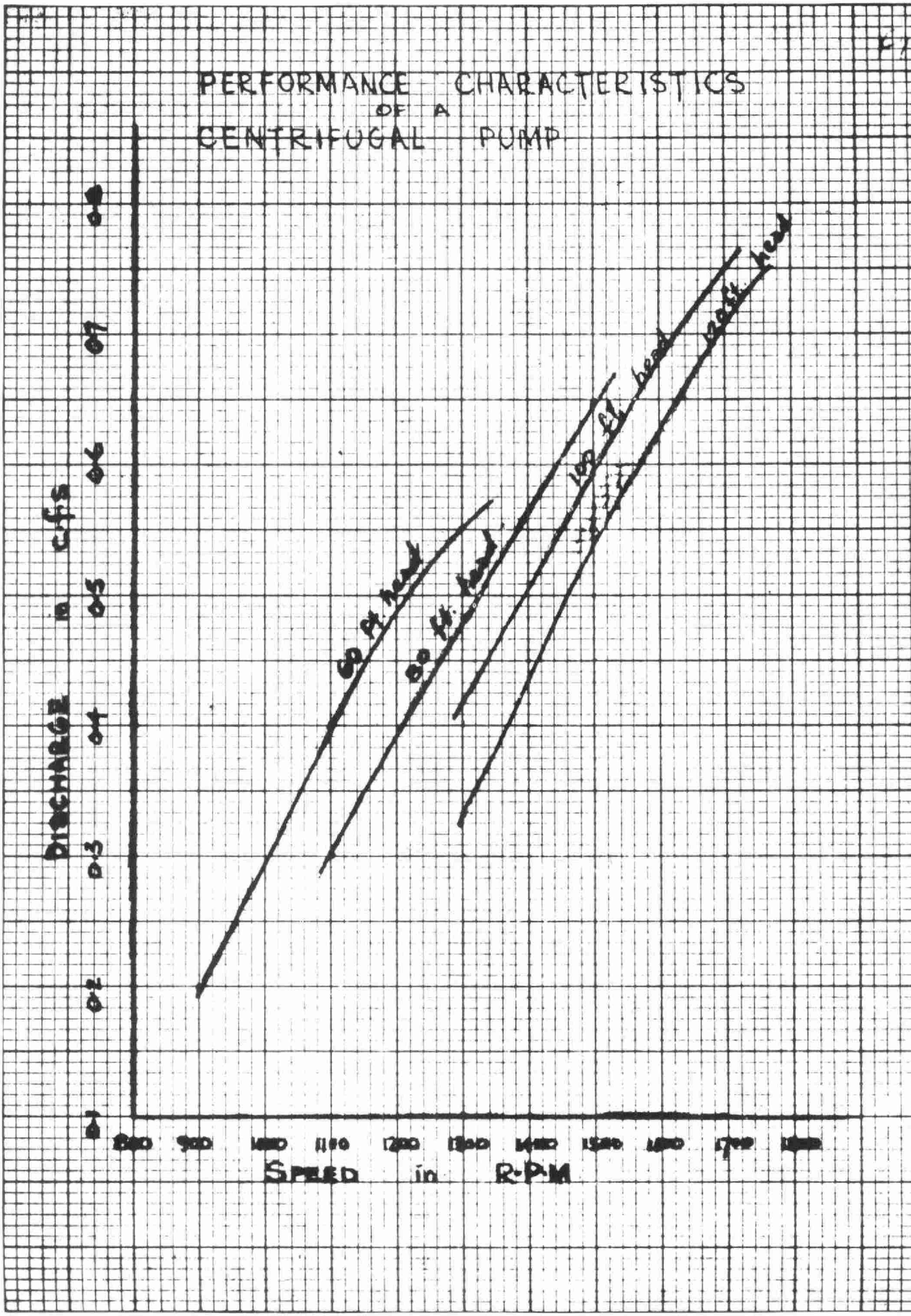
PUMP



RECIPROCATING

PUMP


PERFORMANCE CHARACTERISTICS
OF A
CENTRIFUGAL PUMP.
1700 R.P.M.
1500 R.P.M.
1300 R.P.M.
1100 R.P.M.
900 R.P.M.
HEAD H in feet
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
DISCHARGE Q in c.f.s.


PERFORMANCE CHARACTERISTICS
OF A
CENTRIFUGAL PUMP
DISCHARGE in c.f.s
0.2
0.3
0.4
0.5
0.6
0.7
0.8
60 ft head
80 ft. head
100 ft. head
900
1000
1100
1200
1300
1400
1500
1600
1700
SPEED in R.P.M

RECIPROCATING PUMPS

Theoretically a reciprocating or plunger type pump should discharge a quantity of fluid equal to what is known as the "swept volume".

Example

Suppose you had a sludge pump with a cylinder diameter of 12 inches and a stroke of 8 inches. Then, theoretically, the pump should displace the area x depth $= \frac{3.14 \times 12 \times 12 \times 8^2}{4} = 904$ cubic inches with each stroke. Due to the ineffeciency of the ball checks opening and closing the actual displacement with each stroke is much less.

One of the practical pointers which I would like to point out to plant operators is the idea of plotting results on graph paper. It is only in this way that you can tell when one or more of your readings are not correct.

Principal Devices Used

A head-area meter is a flow measuring device used only for open channel flow or flow in partially filled pipes. It operates on the principal that a constriction or controlled barrier in the flow channel will back up the liquid (to force the liquid past the barrier) creating a higher level or head than the level below the barrier. This head or elevation of the liquid is a function of the velocity of flow and, therefore, of volume flowing through a known constriction per unit time.

Weirs are inexpensive and simple devices, which, however, have definite limits of use. Settleable solids, floating matter, and stringy material tend to deposit from liquids, either in the approach area or on the crest of a weir itself. When this occurs, the flow formula for that particular weir no longer holds and data obtained from it will be in error.

Weirs

A weir consists of a bulkhead or dam containing a recess or notch, through which the sewage flows to fall freely to a level below the crest of the weir; that is, below the bottom of the recess or notch. Weirs are generally used for flow measurement on a temporary basis in sewers, etc.

Weirs are generally sharp-crested so that the liquid will break cleanly from the crest (Figure 9), although broad-crested weirs may be used.

The height of the surface of the liquid above the weir crest is a function of the velocity of the liquid, and, therefore, a function of rate of flow, since the cross-section of the weir is predetermined. The point at which this height (head, h) is measured must be upstream from the weir a distance of at least three times the maximum head to be expected. The reason is apparent from Figure 9, which shows how the liquid "drops" over the weir.

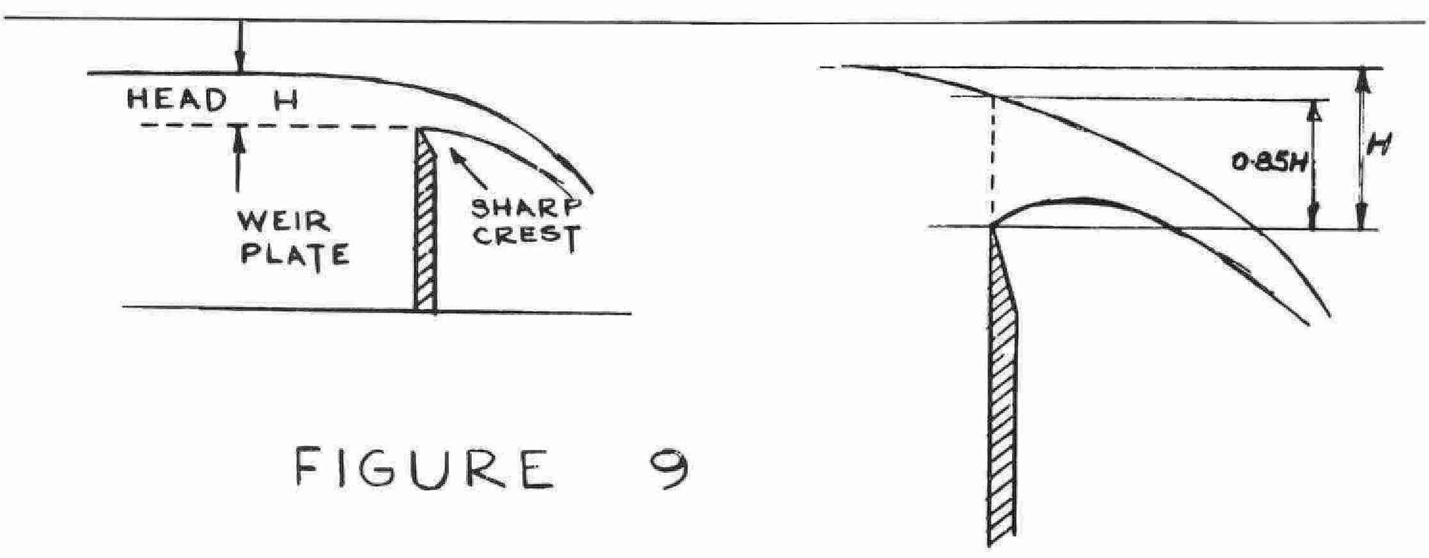
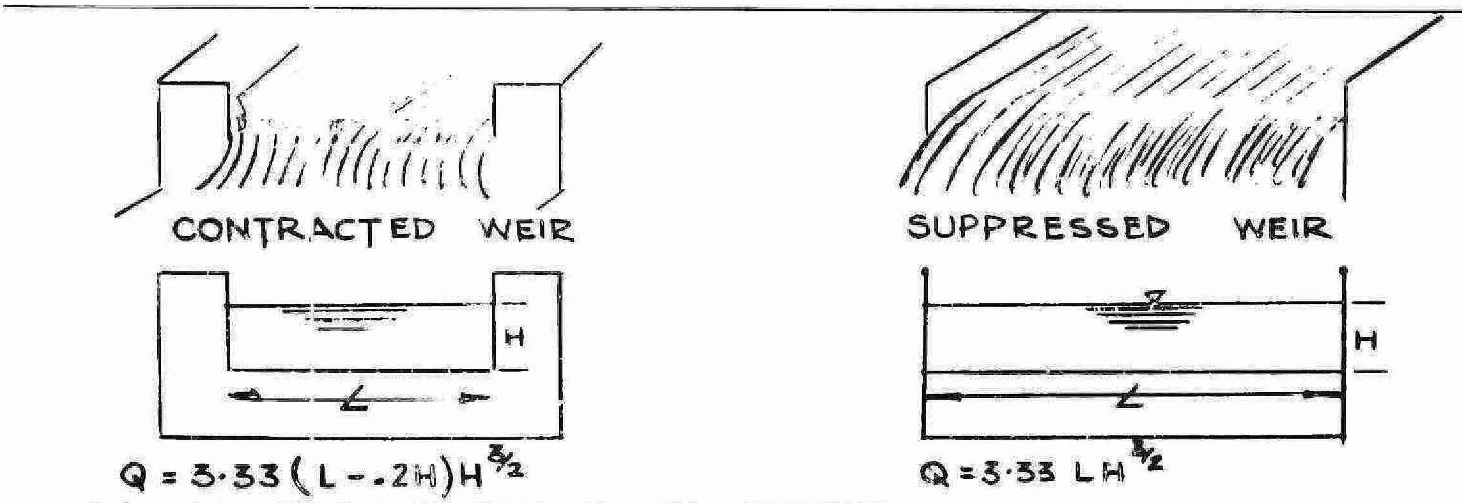


FIGURE 9

RECTANGULAR WEIRS

Rectangular weirs may be constructed in two ways; with ends sharp-edged so that the liquid flow contracts as it passes through (called a contracted weir) or with the ends smooth to allow full flow of the liquid (called a suppressed weir).

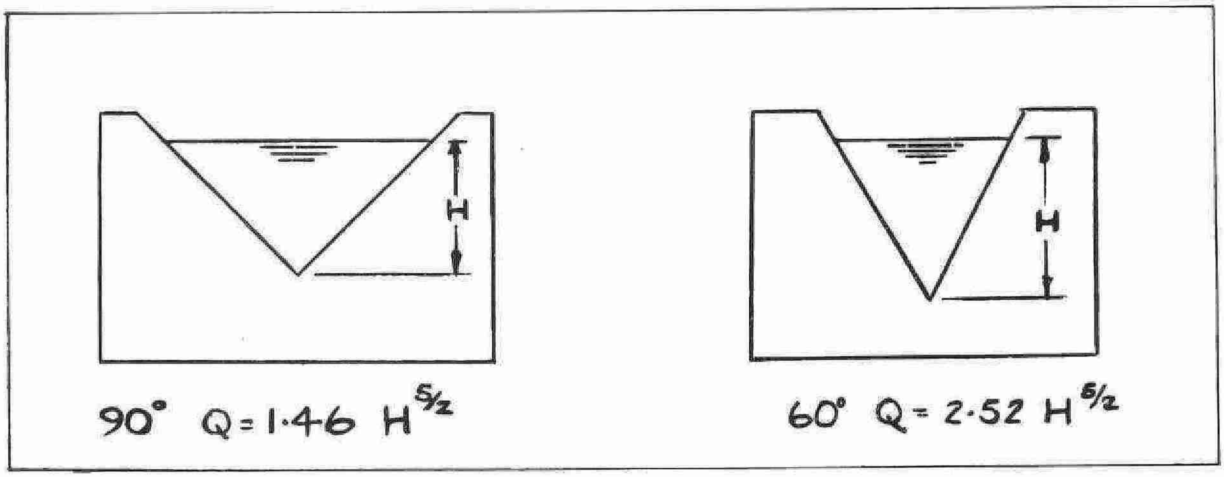


If a contracted weir is used, the value of L must be multiplied by a factor to obtain the true value of L and hence the correct value of Q. (Use 0.1 H less than 1.0 for each contraction. Rectangular weirs are seldom used for measuring small flows.)

V-Notch Weirs

The V-notch weir is best suited for small flows. They are especially recommended for metering flows less than 1 cfs (0.65 mgd) and are suitable for measuring slowly changing flows up to 10 cfs.

The angle of the notch is commonly 90° or 60° but angles as low as 15° may be used for extremely small flows.



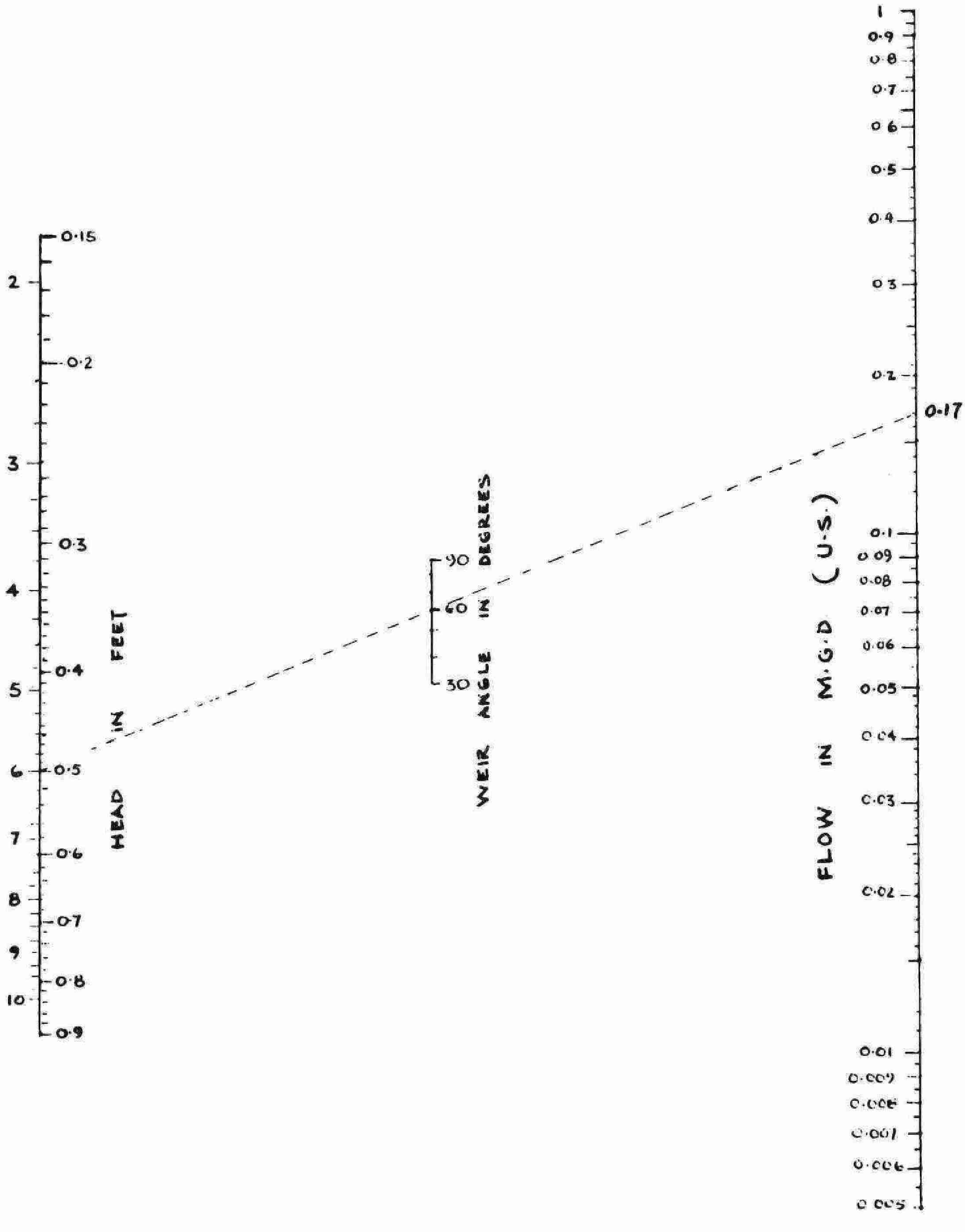
These weirs may be made out of plywood. It is extremely important to make sure the angle of the notch is correct. To insure a sharp edge a piece of aluminum stripping can be tacked to the edge.

WEIRS

For greater accuracy of measurement, all weirs formulas need to be corrected for friction, contraction and other factors. Fortunately for the average operator, tables and charts are available to give a quick means of determining Q if the head over the weir is known.

It is essential that all results from various weirs be plotted on a graph in order that the best curve can be drawn. On the following page six points are plotted but the most likely correct answer is the straight line drawn between all the points.

FLOW IN V-NOTCH WEIRS



PARSHALL FLUME

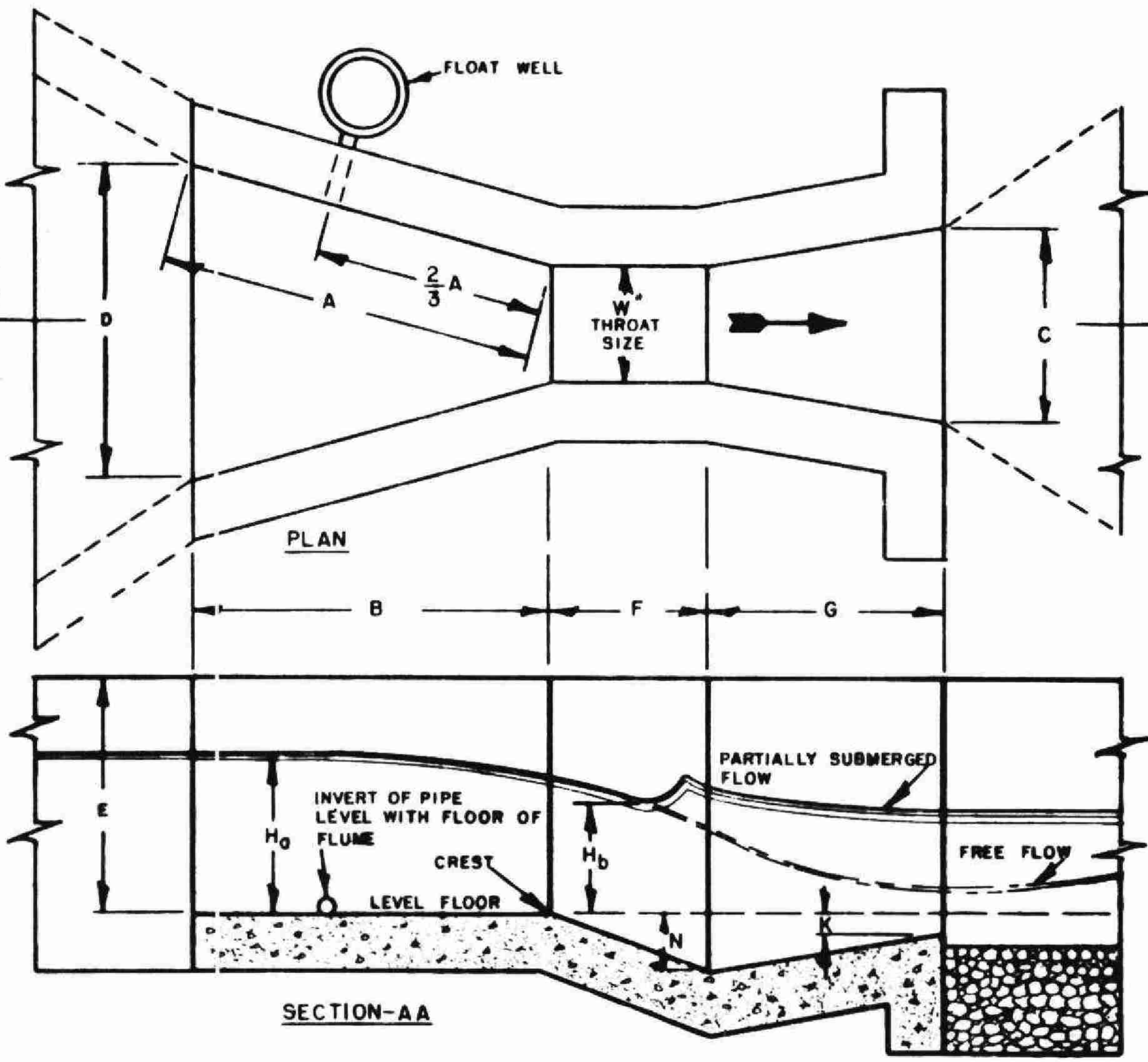
The Parshall flume is a widely used head-area type of meter which you are all probably familiar. Parshall flumes require exacting construction limits, which keep costs high. A stilling well and tap are placed in the converging section at a point two-thirds of the length of the converging section, above the crest of the flume. The tap is at right angles to the wall and at the invert level. Dimensions of Parshall flumes must be held to close tolerances.

Parshall flumes are most useful where a minimum head loss through the device is available, but their accuracy depends on the downstream elevation (head above the floor) being held to less than a definite percentage of that upstream. Under conditions of free flow the elevation of the liquid downstream has no effect on the rate of discharge. Under conditions of submerged flow, where the downstream elevation is sufficient to cause a backing-up, the rate of flow through the flume will be retarded.

Meters for Parshall flumes are calibrated for free flow conditions and will not correctly measure submerged flow greater than certain limits.

SAMPLING

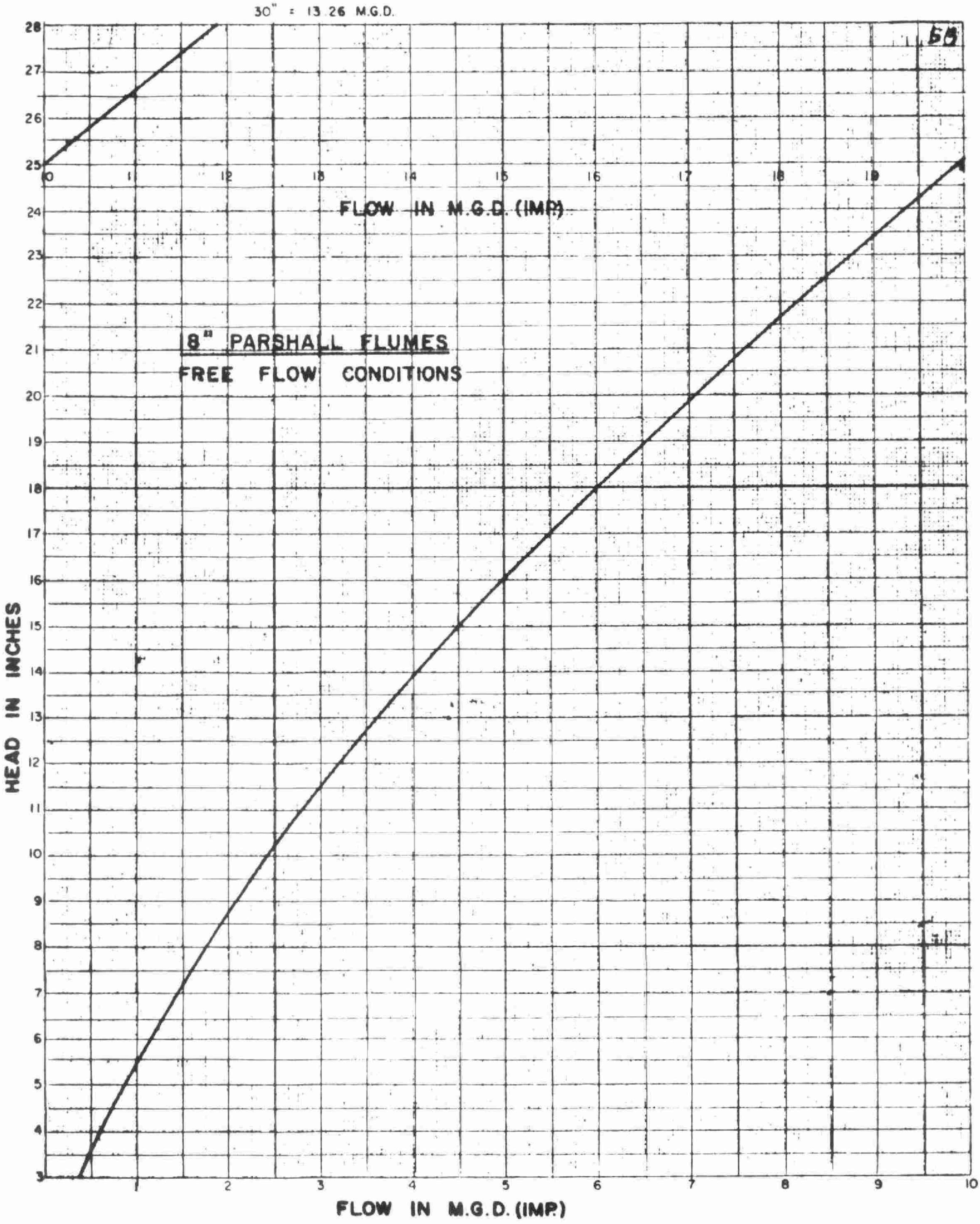
Sampling of a water, sewage or trade waste must be accomplished with proper precautions to secure a representive sample. Too often the error in sampling is inconsistent with the accuracy of the determinations made in the laboratory. It is seldom sufficient to rely on the results of a single (grab) sample. It is more often necessary to use a composite sample, made up of a number of individual samples, or to use the results of analyses of a number of individual or composite samples. It is evident that the results of a laboratory analysis, however accurate that analysis may be, cannot represent an accuracy for the material sampled of a greater degree than the accuracy with which the sample was taken.



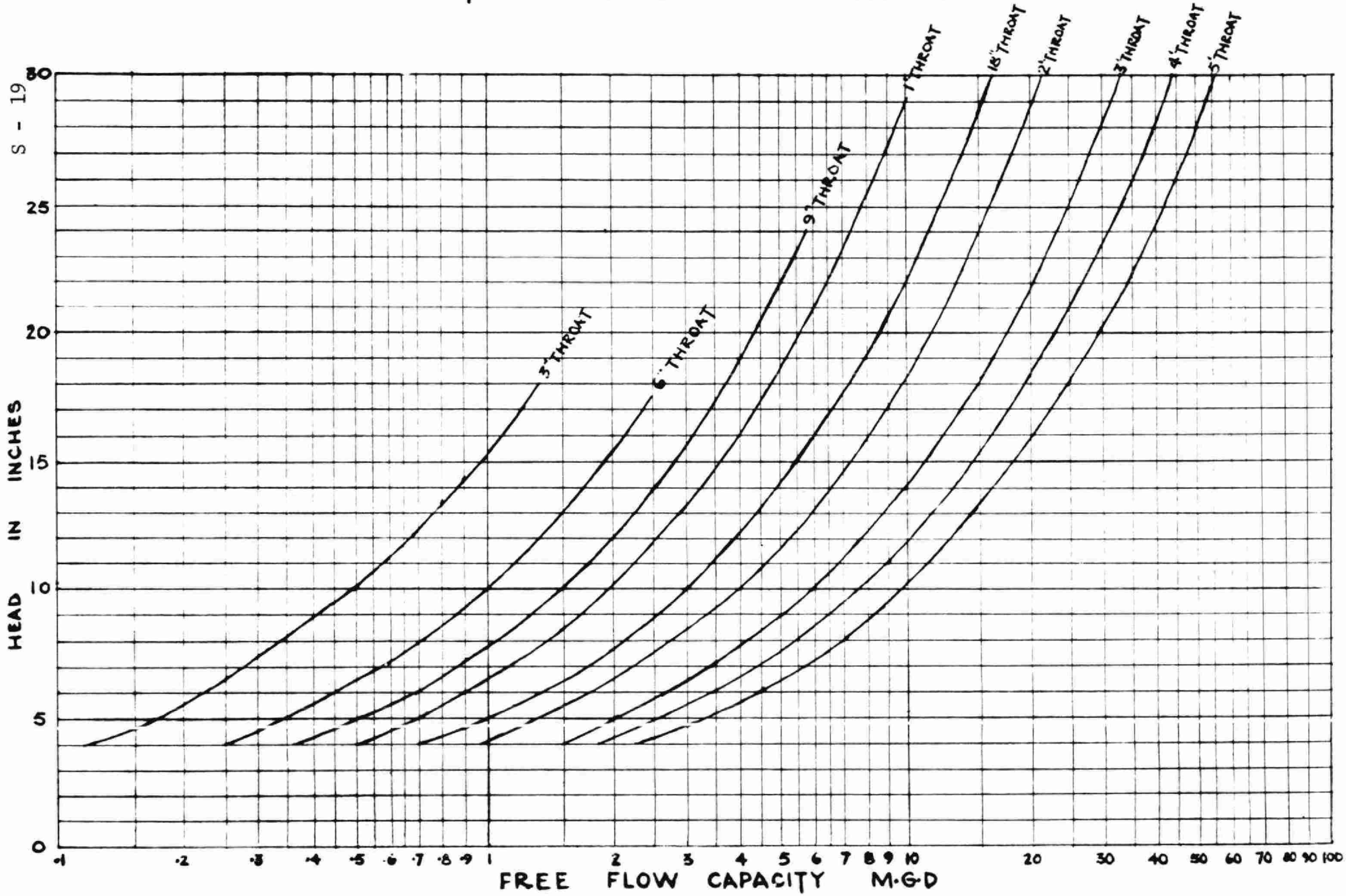
W	A	2/3 A	B	C	D	E	F	G	K	N	*Flume Flow Extremes MGD	
			Dimensions in Feet and Inches								*Min.*	*Max.*
0-3	1-6 3/8	1-1/4	1-6	0-7	0-10 3/16	2-0	0-6	1-0	0-1	0-2 1/4	0.02	1.23
0-6	2-7/16	1-4 5/16	2-0	1-3 1/2	1- 3 5/8	2-0	1-0	2-0	0-3	0-4 1/2	0.03	2.52
0-9	2-10 5/8	1-11 1/8	2-10	1-3	1-10 5/8	2-6	1-0	1-6	0-3	0-4 1/2	0.06	5.75
1-0	4-6	3-0	4- 4 7/8	2-0	2- 9 1/4	3-0	2-0	3-0	0-3	0-9	0.07	10.41
1-6	4-9	3-2	4- 7 7/8	2-6	3- 4 3/8	3-0	2-0	3-0	0-3	0-9	0.10	15.90
2-0	5-0	3-4	4-10 7/8	3-0	3-11 1/2	3-0	2-0	3-0	0-3	0-9	0.27	21.39
3-0	5-6	3-8	5- 4 3/4	4-0	5- 1 7/8	3-0	2-0	3-0	0-3	0-9	0.39	32.57
4-0	6-0	4-0	5-10 5/8	5-0	6- 4 1/4	3-0	2-0	3-0	0-3	0-9	0.84	43.88
5-0	6-6	4-4	6- 4 1/2	6-0	7- 6 5/8	3-0	2-0	3-0	0-3	0-9	1.03	55.32
6-0	7-0	4-8	6-10 3/8	7-0	8- 9	3-0	2-0	3-0	0-3	0-9	1.68	66.89
7-0	7-6	5-0	7- 4 1/4	8-0	9-11 3/8	3-0	2-0	3-0	0-3	0-9	1.94	78.46
8-0	8-0	5-4	7-10 1/8	9-0	11- 1 3/4	3-0	2-0	3-0	0-3	0-9	2.26	90.16

***Extreme minimum and maximum capacities of flume; the actual measuring range depends upon the type instrument selected (see page 7) and will lie within these extreme limits.**

Fig. 3 Parshall Flume Dimensions


30" = 13.26 M.G.D.
5B
FLOW IN M.G.D. (IMP.)
18" PARSHALL FLUMES
FREE FLOW CONDITIONS
HEAD IN INCHES
FLOW IN M.G.D. (IMP.)

CAPACITY CURVES FOR PARSHALL FLUMES



ENGINEERING DATA

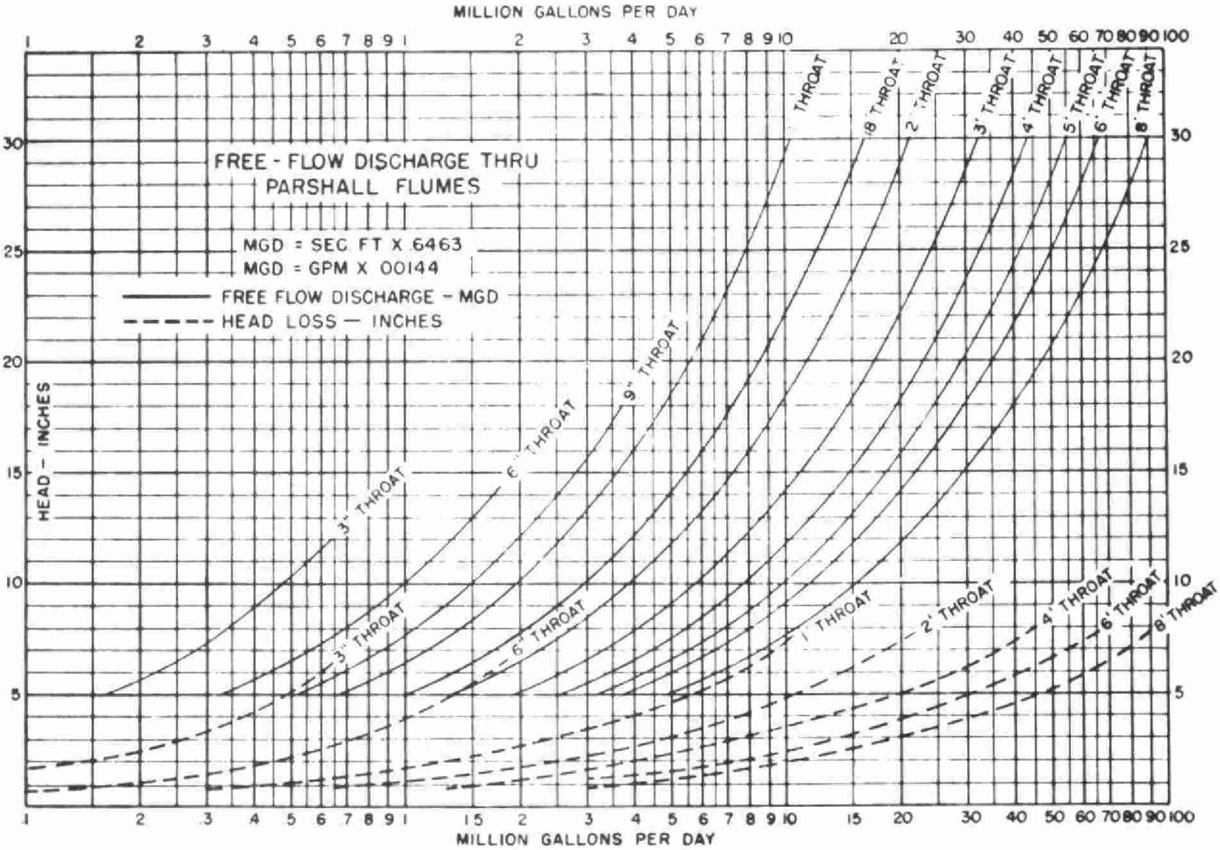


FIGURE 21 — Capacity curves for Parshall Flumes.

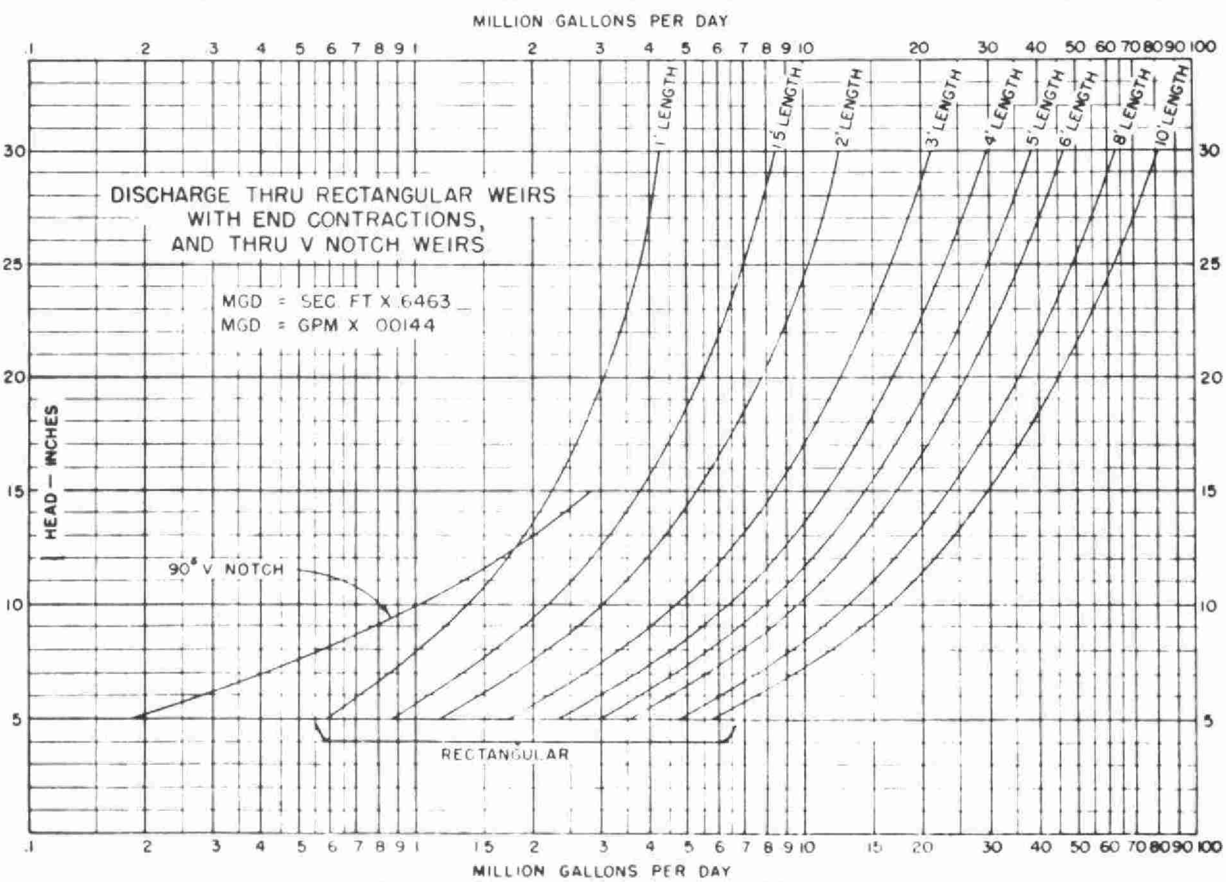


FIGURE 22 — Capacities of Rectangular and V-notch Weirs.

In the collection of representative samples, the following points must be taken into consideration:

1. The character of the laboratory examinations to be made.

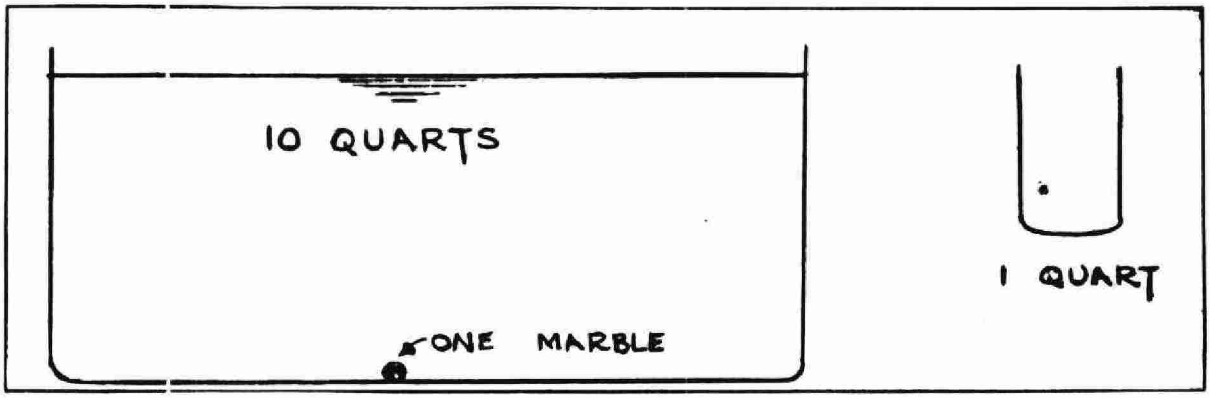
2. The use to be made of the results of the analysis.

3. The character of the material sampled and the variation in character over the period of sampling.

4. The variation in the rate of flow over the period of sampling.

The meaning of a truly representative sample can be illustrated as follows:

Suppose you had a large tank which contained 10 quarts of clear water plus one marble.



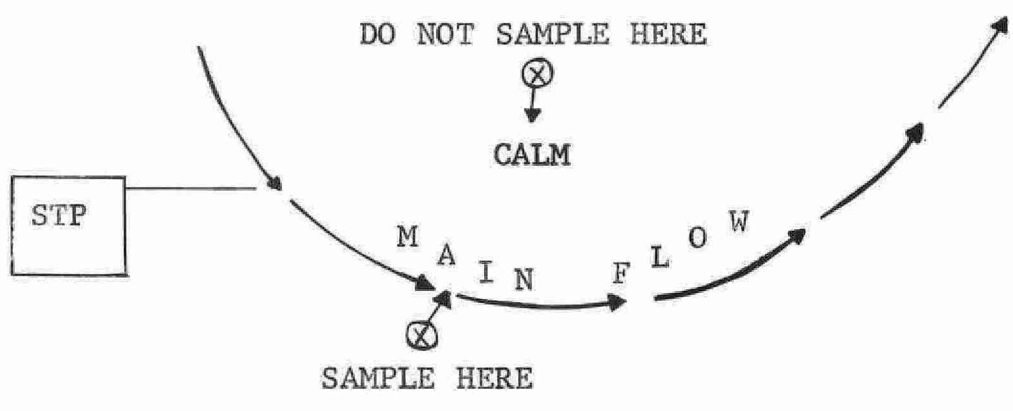
If you were sampling this large tank with a one-quart sampler, you should obtain water only, nine times out of every ten to have a truly representative sample. If you obtained water only on the first sample, this would indicate that there are no marbles in every quart of water which is 90 per cent correct. If you obtained a marble in your first sample, this would indicate that there was one marble for every quart of water where actually there is only one marble per ten quarts.

By the law of averages in the long run you should pick up the marble one time out of every ten or for every 100 samples obtained, 10 should contain a marble.

Flowing Streams

Flowing streams are subject to considerable variation and in most cases require composite sampling or the averaging of the results of the analyses of a large number of samples. Samples from a stream should be taken at a point which most nearly represents the conditions in the stream. This point should be within the flowing channel and at about mid-depth, and not in brackish areas held back by weeds. Wide, deep streams may require the collection of samples in a number of verticals across the stream and at several depths in the verticals in order to obtain a representative sample. Composite samples made up of hourly individual samples taken according to flow are usually considered as representative of the stream condition.

It is a good idea to obtain samples from the receiving stream both above and below the outfall sewer. By doing this it is possible to find out what effect the sewage is having on the quality of water in the stream. It is essential that this sampling is done correctly. Samples of water taken above the outfall must be truly representative of the stream and it must be uncontaminated by sewage from the outfall. It is a good idea to sample at a point one or two hundred yards upstream where there is no possibility of contamination from the outfall. The downstream sample should be far enough downstream that the sewage is well mixed with the flow of the river. You must be careful to make sure that any changes in the stream quality are caused from the STP and not from any industrial or storm outfall.



Sewage and Sewage Treatment Plants

In sampling influents and effluents from sewage treatment plants or sewage from a sewerage system it is particularly important to take composite samples. The character of sewage is too variable in short intervals of time to place any reliance upon individual samples. Composite samples should be made up on individual samples which vary in size according to the relative flows at the time they are taken.

It is desirable to extend the taking of the composite over a 24-hour period or, in smaller plants, at least over several hours. A better study of plant accomplishments may be made by dividing the 24 hours into two or more groups and obtaining a composite for each group. In large plants a good plan is to take a composite for each shift. You should keep a record and indicate on the bottle the hours over which the composite was taken.

Sewage samples may be readily collected by means of dippers or cans several inches in diameter. The dipper should be immersed well into the sewage and the sample taken at about mid-depth.

One of the most convenient methods of sampling is to use a glass milk bottle suspended on a pole. The milk bottle can be easily detached by means of a clip on the pole which enables the sampler to reach into tanks and channels with less danger of falling in or losing articles from your pockets.

The individual portions can be combined in a single bottle as collected. At some OWRC plants, the individual samples are added to a gallon jug.

For instance, if a small plant was being sampled over a period of eight hours and the flow was relatively constant over this period, the sampler would take approximately 1/3 of a quart each hour for eight hours, and put them into the gallon jug. At the end of the sampling period there would be approximately 8 x 1/3 = 2-2/3 quarts in the jug. The jug would then be shaken up and the contents poured into a 40-ounce bottle to be sent to the laboratory.

A more difficult problem of sampling presents itself when a 24-hour composite must be taken and the sewage flow varies considerably. To set up a proper sampling routine, it is advisable that you know in advance the probable variations to be encountered and then obtain samples in proportion to the flow.

Another method of composite sampling is to collect a single sample every time and record the flow at that time. At the end of the sampling period all samples can be poured into a large jug in proportion to the flow at the time of sampling. The large composite can then be properly mixed and then poured into a smaller sampling bottle for shipment to a laboratory.

Biochemical Oxygen Demand

BOD samples must be free from all preservatives. When samples are composited, the individual or composite samples should be chilled immediately to 3°C. and kept at this temperature during the compositing period. In samples stored at room temperature, the BOD may drop 10 to 40 per cent in six hours, but in some cases it may rise.

One of the most common causes of errors is the practice of leaving the composite bottle sitting out in the hot sun during the compositing period. Where samples cannot be readily chilled in a refrigerator, they can be immersed in a cold water bath.

Great care must be taken when samples are being shipped to the laboratory. It is highly advisable to arrange that the sampling period ends just previous to the express shipment. This arrangement cuts down on the length of time the samples sit in the freight office or at the plant.

Sampling for Dissolved Oxygen

It is necessary to make dissolved oxygen determinations on samples at the time of collection and no composite samples can be taken. Samples should be taken with extreme care so as to avoid contact of the sample with air. In order to facilitate the taking of dissolved oxygen samples, a

sampling can should be used. This can should be of such a size that the displacement in the can is at least four times that of the sample bottle. The use of this can prevents contact of the sewage with air.

Sampling of Sewage Sludge

Samples of wet sludge being drawn from a tank should be composited from individual samples. A regular schedule should be adopted for individual collections at various times during the drawing operation. Five minute intervals are often used. The individual samples should be placed in a large receptacle and well mixed, a smaller sample being taken for the laboratory.

If sludge from a drying bed is to be sampled, a composite should be made up by taking individual samples taken from the full depth of the material in each section. This may be done by forcing a one-inch thin-walled metal tube into the sludge the full depth, withdrawing the tube and removing the adhering sand. A plunger placed in the tube will facilitate the removal of the sample. All of the individual samples should be well mixed. The final sample for analysis should be obtained by quartering the composite. Quartering consists of dividing the pile on the paper into quarters, discarding opposite quarters, again mixing, quartering and discarding until the required size is obtained.

OPERATOR PUBLIC RELATIONS AND PLANT MAINTENANCE

C. W. Perry

Assistant Director
Division of Plant Operations

The subject that I am to give this afternoon is entitled "Operator Public Relations and Plant Maintenance". This is really two subjects and one could easily spend an hour on each. However, in this first course, the intent has been to give you an introduction to as many subjects as possible. We, therefore, will only touch on the topics and, it is hoped, more time will be given to elaborate further on these subjects in later courses. They are both extremely important to the successful operation of a sewage treatment plant.

PUBLIC RELATIONS

I first wish to discuss "Public Relations" and how the operator fits into the general public relations picture in his municipality. Also, how public relations can be used to the benefit of the operator.

Sewage treatment is a difficult business for a number of reasons.

Firstly - It is costly and the average citizen in a municipality may not always be sympathetic to this cost -- he cannot see any direct benefit from it. Any type of bill is a nuisance but, for instance, take a water bill. For his money the householder gets clean, pure water in his taps; he can water the lawn, or wash his car. He feels he is getting something for his money. But, what about a sewage bill? This is something that he cannot easily see a benefit for. Therefore, he is not anxious to pay it.

Our experience has shown that the average person does not care a hoot about sewage treatment as long as the waste is carried away from his doorstep.

Of course, there is always the exception -- the public spirited citizen, or the sportsman or the conservationist who is genuinely interested in clean streams. But I am speaking of the average citizen.

Take a municipality that has always had sewers which discharged directly into the receiving waters. A treatment plant is now built, and the householder now has an increased tax bill or extra sewage bill, or both, to pay for financing and operating the new plant. A good public relations programme is necessary to sugar-coat the bitter pill.

Another need for good public relations on the part of the plant operating staff is with its neighbours.

Sewage treatment plants cannot always be located in remote areas. As we become more built-up and more treatment plants are constructed, it will become necessary to put more and more plants in built-up areas.

I do not care what anybody says, sewage plants smell! They, like anything else, have a characteristic odour, even when operating properly. This odour may not be objectionable to you, but it may be to one of your neighbours. Here is where good public relations can help you overcome some nasty situations, even when you have had an accident at the plant, and you know the odour has been bad.

The next group where good relations are important is with the municipal officials. One should obtain the support and good will of your city officials. This lays the groundwork for good public relations. It is most important that the officials understand how your plant functions, what its needs and problems are, and how it is planning for the future.

Keep your officials informed. Nothing annoys an elected official more than to learn first about your problems by reading it in the newspaper.

Our experience has shown that the sewage plant is a good place where councils can cut their budgets. Therefore, if you are going to obtain the funds necessary to keep the plant adequately staffed and in good repair, then a good public relations job is necessary. Some may say this is beating your own drum. Maybe so. But if councils know how important sewage treatment is, how important it is to have a good treatment plant, well maintained and well operated, they will not likely be inclined to cut the budget below a safe level.

Some of the municipal plants we have taken over for operation have been merely a shell - repairs and maintenance neglected, under-staffed and poorly operated. Why? Well, insufficient operating budgets have been the direct cause. The indirect cause - poor public relations between the operating staff and council.

The last area for good public relations which I wish to touch on in this lecture is with the operating staff. I believe that most of you here are chief operators or superintendents.

It is my firm conviction that the relationship between a chief operator and his men can either make or break a plant.

Well, so far we have talked about when good public relations are necessary, but we have said little about how to do this. I would, therefore, like to spend some time on how to encourage good public relations.

The secret of good public relations is to take the public into full confidence by making correct and honest statements. You must merchandise what you are doing.

What are the tools available? They are: the press, radio, T.V., public meetings, talks before civic and other organizations, such things as regular guided tours, visits by school classes, a large flow diagram on the plant wall, a visitor book, a booklet describing the plant and system, street signs to tell what is being done on a project, exhibits and posters in the office lobby or city hall, good housekeeping, attractive signs naming all equipment, a float in the annual parade, display at flower and garden show, etc.

Friendliness begets friendliness. One satisfied citizen can do more to improve public relations than a dozen ads. Teach the necessity of courtesy -- it is the cheapest commodity in the world. Good will is the most priceless asset a business or utility can possess.

W. S. Foster, Editor of the "American City" offers the following suggestions:

1. He would eliminate the words sewer and sewage from any departmental title. He would also have a single department of water with divisions of supply and disposal.

2. Take down "No Admittance" signs and replace them with "Welcome" signs. Post the visiting hours below "Welcome".

3. Encourage trips through the plant by service clubs, school children and others.

4. Allow the use of suitable grounds for recreation and picnic areas.

5. Enclose with the monthly bill an extra folder telling something about the plant and system. (A leaflet about future extensions or the care of lawns, shrubberies and trees will be appreciated.)

6. On complaints, Mr. Foster would work out a detailed system of handling, including names and addresses, nature of complaint, name of person who received the complaint, to whom it was referred, and action taken. Follow-up would be with a letter of thanks, describing the action taken.

Much of what I have said above can be used to improve relations with those people living in the area. The main causes of complaint by these people are noise, foam and odour. We have found through experience that a little psychology used on these people works wonders. A personal visit by the plant superintendent to each of the houses to solicit their assistance in overcoming the problem has been successful in every instance. We ask them to give the plant a call whenever they have a complaint so the operator can see at once where the odour is coming from, or the foam, so he can take immediate action to remedy the condition and prevent future occurrences. I believe Mr. Kauppinen earlier went into this in detail in his lecture. A personally conducted tour of the plant for any complainant, with complete explanation of the processes being carried out, and the problems being encountered, often makes these people more sympathetic to the plant operation.

Regarding the relationship with staff, much can be said. I mentioned earlier that a chief operator can make or break a plant. A plant superintendent may be the best technically trained man going, but if he lacks imagination and administrative ability, his staff will not respond.

It is amazing what good leadership can do. Firm orders, given in a pleasant way, definite operating routines, a bulletin board, and written instructions, all help to promote a smooth running organization. Some chief operators are able to inspire their men, give them a purpose, and introduce a team spirit among the staff. The results are amazing. The men take a real interest in the work, no longer become clock watchers, and have a pride in their plant and chosen profession. They cease to merely be hourly employees.

Self-improvement should always be encouraged, whether this is by night school, correspondence courses, or other means. Some of our plants have introduced weekly training sessions during the winter months. Here, for one night a week the men return to the plant on their own time for discussions, instruction, or hear outside speakers. These have been invaluable in bringing

the supervising and operating staffs closer together.

HOW TO BUILD GOOD PRESS RELATIONS

Good press relations are important for a number of reasons. A number of tips on how to improve these have been assembled which are as follows:

1. Newspapers exist to inform the public, the same public you serve.

2. Do not confuse public relations with publicity. Just getting space in the local paper is not enough. It must be filled with planned, factual information.

3. Keep the newspaper informed on what is happening. The time to get acquainted is when things are going well.

4. Know the city editor. He will tell you how news is handled and probably assign a reporter to cover your department. The reporter will be eager to work with you in developing news from your department. Don't go over his head, always tell him first. Don't hold back, give him all the facts whether they are favourable or not.

5. What is news? News items are: unusual operating conditions, emergencies, new facilities, rate changes, long-range plans, expansions, annual reports, regulations, participation in meetings, unusual jobs, employee activities and human interest stories.

6. Newspapers have deadlines; keep them in mind. Get information a reporter needs if you do not have it at hand. Don't complain about an unimportant error.

7. Stories in news columns are more likely to be read than ads. When advertising, use display type. People won't wade through 250 words to gain a thought or point. Humanize the advertising. Dramatize financial statements.

8. Whether your relations with the press are good, bad, or indifferent depends largely on you.

It must be remembered that ads, displays, and booklets cannot repair completely the injury done by a thoughtless employee.

There are many other items I would like to include here, but time does not permit. Maybe, a future lecture could be enlarged to include --

How to get along with people - fundamental techniques in handling people. Ways to make people like you; ways to win people to your way of thinking; etc.

PLANT MAINTENANCE

Plant maintenance is a very large subject and, here again, too large to adequately cover in this brief hour. Preventive maintenance of pumps and equipment is being covered in other lectures. I would like to confine my remarks today to the more general terms of how plant maintenance can affect the public relations covered in the first part of the lecture.

The objectives of sewage treatment are:

1. to produce a good effluent,

2. in doing that, to cause no nuisance to the neighbours around the plant, and

3. to make the plant clean and attractive. To achieve each of these objectives requires proper maintenance.

There are three types of operators:

1. The man who expects everything to be done for him. If something goes wrong, he wants somebody to come and fix it, supply a new part or buy a new machine.

2. The "haywire" type who "keeps her going" by patching the equipment. Year after year there are more and more patches, but he manages to keep the plant going. The operator may be proud of his handiwork, but the plant becomes run down and, when another operator comes in, he is amazed that anyone could let equipment get in such a condition.

The "haywire" type of operator is admirable, I grant you, to a certain extent, but the man I want is:

3. One who has a vision of what he can make of his plant. He wants a plant that just sparkles from the road, through the grounds and buildings, to the final effluent. Of course, he should be able to use haywire when necessary, but he is not going to be satisfied with that.

At this point I wish to mention the responsibility of the operator in regard to funds. Sometimes, I think the operator feels that he has nothing to do with the money; that it is not his concern. I admit the operator does not have the last say in regard to money, but he certainly has the first say and, if he doesn't give voice to this, he probably won't get what he needs to run his plant. It is obvious he won't get it if he doesn't ask for it, but then he must ask for the money correctly. He shouldn't just say, "I think I should have $3,000 for improvements to the plant next year." He should study his plant and decide what he should do in each part of it during the next year with regard to painting, building repairs, grounds, roads, equipment repairs and replacements, tools, etc. When he writes his report, he should give information as to the conditions that exist, stating why he needs the

money for each particular item and what will be accomplished. In some cases, this should be done in consultation with his superior, the engineer or superintendent.

The second responsibility is to make the best use of the allotment of funds that you are given and make sure that it is used to the best advantage of the plant and the community.

Thirdly, if you don't get all you ask for, you should improvise and carry on with your plans the best you can. In some cases, I feel that the plant operator is too close to his job, and he thinks, "The only way I can handle this is to get a new piece of equipment:" and, when his request for that is turned down, he had to look at the problem differently. I remember a professor who used to say, "If you can't solve a problem one way, go at it in exactly the opposite way." I think this often proves to be a good approach to problems.

Where plants are only attended during the day time, it is absolutely necessary to have the plant completely fenced to keep children from damaging the plant and also to keep them from falling into the tanks or getting into the sludge drying beds. In one case, children threw some lengths of pipe into the final settling tank, which jammed the sludge collector and bent one of the shafts before the shear pin broke. Stones and other items thrown into the primary or final settling tank can block sludge lines.

With regard to cleaning in general, I think it is most important that a sewage plant should be kept just as clean as it is possible to keep it. I expect the cleanest room in your house is the bathroom. Your wife probably cleans the bathroom once or twice a day, whereas she may clean the living room only once a week or less. The bathroom is kept clean because it is subject to the most dirt. For exactly the same reason, the sewage plant must be kept clean, because it is subject to so much dirt.

To keep it clean requires work and organization. I expect you are quite familiar with work, but I would like to comment on organization. The first thing which I consider important is the establishment of a routine of cleaning to cover the whole plant, to clean routine dirt so that, within a period of time, say a week, every part of the plant is cleaned. Then, when you have worked out the routine required, be sure and follow it. Secondly, make a practice to clean up what might be called "special dirt" right away. Frequently, when a sludge pump is dismantled or a check valve cleaned, the effort is placed only in getting the plant operating properly again, and spilt sludge or grease is left where it is until it is spread around and makes a mess of a large part of the plant. In such cases, cleaning up should be considered an integral part of the emergency repair job.

In regard to grounds, it is important, when you come in to the plant each morning, to look at it from the point of view of an outsider. There may be papers on the lawn, which can be easily picked up. If left there, they would create a bad impression. Some equipment or material may have been left in a prominent place, which should be put away, or moved to a less prominent location. If we could every so often take the point of view of the outsider with regard to all phases of the plant, taking an objective point of view, we could see where we could improve the plant just from a general housekeeping point of view.

Then, of course, it is important to keep the grass neat and trim. Don't forget outside the fence, if there is a fence. We sometimes assume that anything outside the fence is not our responsibility. Most householders cut the grass and clean right out to the road curb. You don't want the appearance of your plant spoiled by a neglected boulevard.

Buildings must be kept clean on the outside as well as inside, properly painted, and the windows clean. A plant with dirty windows looks deserted and run-down. Keep eavestroughs in repair for the sake of the appearance of the building and to prevent the roof

water spoiling the landscaping and the foundation plantings. Inside, the buildings should be orderly. You should have a place for each tool, and each should be in its proper place when not in use.

Good maintenance, I feel, is built on establishing a proper routine of inspections and checks and then of keeping records of the maintenance inspections and the work done. It is no use doing a maintenance job on, say, a sludge pump, and then a month or so later wondering "When did I last look at that sludge pump"? It is just as important to keep the records of maintenance as it is to keep the records of operation. The old saying "An ounce of prevention is worth a pound of cure", I think, is very applicable to maintenance of sewage treatment plants.

OPERATION AND MAINTENANCE OF SEWER SYSTEMS

R. E. Brown

Operations Engineer

INTRODUCTION

I have recently estimated that to install a new sewer system to service a small municipality, would cost in excess of $400.00 per capita or $4,000,000.00 per 10,000 persons. Perhaps because these utilities are relatively out of sight, few municipalities practice the adequate operating and maintenance procedures warranted by their investment value and public health importance. Commonly, only when an emergency arises is any action preciptated and then usually only after a householder has had the shocking experience of having his basement flooded from the sewers. If he knew that this might have been avoided by adequate municipal operations, he would be even more shocked.

It is important, therefore, that steps be taken for the prevention of the inconveniences and damages, together with the efficient operation of this utility that represents such a large investment to the municipality.

SEWER CLEANING METHODS

A sewer system consists of sewers, manholes, pumping stations and other appurtenances. A sewer's capacity to carry water-borne wastes is dependant primarily on its cross sectional area and the slope on which it has been laid. It is hoped that the sewer was designed and installed at a grade to produce a minimum flow velocity of two feet per second to prevent sedimentation, however, sedimentation often does occur and where sediment, rocks, rags, lumber, roots, grease or other waste products reduce the cross sectional area, the sewer department should embark on an active maintenance program.

In the small municipalities the works superintendent is commonly expected to be a jack-of-all-trades and, depending upon the attitude of council, he may be allowed an assistant to do some of the heavy work. Here, sewer cleaning is commonly performed on a "wait for a complaint" policy and is usually accomplished be means of wooden rods

manipulated from within the manholes.

With the increasing size and awareness of the municipality, a crew of men is often established for both water main and sewer work and hydraulically propelled sewer cleaning devices appear. A rotating nozzle, cutter or "ferret" attached to a fire hose, an inflated rubber ball, various hydraulic scrapers, a flush bag, sewer hoe, sand cup, and sewer scooter, all have been and are still used, but are considered by some authorities to be obsolete.

During this phase of development, flexible steel rods may also appear with various root cutter, sand auger, corkscrew attachments, together with power take-offs which impart a rotating action for improving this rodding and cleaning of the sewers.

Eventually, the municipality's size and/or enlightenment, results in the purchase of bucket machines. Here, winches at adjacent manholes pull a bucket-like attachment through the sewer to allow surface disposal of the extraneous material.

It is necessary to rod the sewers to place the winch cable between manholes. As the number of bucket machines in a municipality increases, regular rodding machines become inefficient. To overcome this limitation, and to provide a means for rapid clearing of emergency blockages, separate rodding machines capable of placing rods at a rate of up to 100 feet per minute are ultimately acquired.

These phases have been presented to indicate that the basic sewer cleaning equipment and associated staff are usually dependant upon the size and/or the enlightenment of the municipality.

OPERATION AND MAINTENANCE RECORDS

It is important that each municipality realize the necessity of adequate operation and maintenance procedures and records. The "wait for a complaint" attitude is to be avoided and preventative maintenance is to be desired.

Inspections, therefore, are an integral part of any program. When trouble areas are discovered, inspections and cleanings should be scheduled on a more frequent basis

than that used for the rest of the sewer system.

An accurate record of the location and depth of the sewers, manhole covers and other appurtenances is essential. Complete as-built maps and plans should be available for all portions of the sewer system including the location of all wyes installed for future connections. These plans should also show all other utilities and buried cables known to be in the area, and should be kept up to date. Area maps are useful to indicate the related sewer areas and systems. An overall map can be used to indicate the frequency and completeness of the cleaning program.

In addition, it is desirable to maintain written records on the conditions found at the time of inspection, the work performed, the time taken, any special problems encountered and the date. Some examples of forms used in two different municipalities are appended to this paper.

NEW EXTENSIONS

When extensions are made to the system, care must be exercised to avoid allowing silt or sand or other construction debris to enter the original system, which would upset the cleaning program. This may be accomplished best by temporarily sealing the sewer at the junction manhole. Building connections improperly installed in new and established districts can also contribute extraneous material to the system. All unused lateral connections should be properly sealed. It is a temptation to builders and drain layers to dispose of all silt laden excavation water to the sewer, therefore, this activity should be controlled. Care should also be taken to ensure that building downspouts are not allowed to contribute to separate santiary sewers. To these ends, building connection permits should be required to ensure a proper installation and to provide a record of the connection's location. A plumbing permit should similarly also be required.

MATERIALS IN SEWER CONSTRUCTION

In both sewer and building connection construction, the most efficient materials should be used to minimize future problems. New tight, flexible joints are allowing appreciable progress towards limiting infiltration and root penetration of sewers and connections. With the increased cost to municipalities for sewage treatment, every effort

should be made to minimize the amount of infiltration flows requiring treatment. There is little advantage in specific treatment plant design if sewer laying and jointing is to be a haphazard process. Many treatment plants have been prematurely hydraulically overloaded in recent years due to abuse in the construction and use of an otherwise good sewer system.

CELLAR FLOODING COMPLAINTS

Of interest to all municipalities is the proper processing of cellar flooding complaints. It is usually considered that the municipalities' legal responsibility in regard to building connection operation, terminates at the private property line. Sometimes, however, the location of a blockage is in doubt. To avoid later litigation, it is common to insist that no claim for damages will be entertained unless the sewer department is called to investigate before any action is taken by a plumber, in order to ascertain if the blockage occurred on municipal or private property. A small service charge could be made for this work. A crew should be dispatched promptly to aid the homeowner even to the extent of assisting in cleaning and removing articles which may have been damaged or will be damaged if left in place. Bylaws may be enacted to deny acceptance of responsibliity, by performing such assistance by the municipality. A clean-out on the building connection at the property line with a riser to the surface would allow rapid evaluation of the location of the blockage. If the connection was dry there, the blokcage would be on the private portion. If it were found to be filled with liquid, the blockage would be on the municipal portion. Also, the clean-out would then allow the entrance of sewer rods at this point to clear the blockage. Alternately a clean-out just inside the residence should always be required.

ROOT BLOCKAGES

In treed areas, roots are often the worst cause of blockages. In clay soil, deep root penetration usually is not encountered; however, in sandy soil during the summer season, the tree roots will extend to the sewers when they exert severe pressure to enter the joints. Therefore, root-proof connections are necessary and in these known trouble areas, programs are common, to replace original materials with more root-proof and water-tight types.

BUCKET MACHINES

I have suggested that the acquisition of equipment and proper programming is relative to the size and enlightenment of the municipality. Probably, the most significant step forward that the growing municipality will take in sewer cleaning will be the acquisition of the bucket machine. Prior to this time, manual labour, together with the assistance of hydraulic aids, will have been the rule. With these methods, that rely on the flush action of a flow of water, an attempt is made to capture the disturbed material at the downstream manhole, however, a large amount of material usually escapes to settle further downstream in the system. Flushing operations also produce an extra hydraulic load on the treatment plant, together with sudden increased grit and suspended solids quantities, odours and biochemical oxygen demand. If these methods are used, some attempt should be made to determine the seriousness of the treatment plant overload.

These methods really offer only partial relief and the cleaning program is not really effective until the material is physically removed from its initial position in the sewer for surface disposal, by units such as the bucket machines.

When a rodding machine is used in connection with several bucket machines, temporary cables or wires are sometimes rodded into the sewers in advance of the machines to be used shortly to speed up this work. Sometimes these bucket sewer cleaning operations are concentrated during winter months when permanent staff is more readily available.

SEWER ORDINANCES

If sewer maintenance and sewage treatment is to be effective, sewer ordinances are necessary. The discharge of harmful industrial or commercial wastes should be controlled and where excessive sewer cleaning will be required, it should be reflected in the individaul connection cost or service rate. Inspection holes or manholes on these connections will allow inspection of the effluent from these problem sources. Industrial waste and sewer use bylaws are becoming common in municipalities that have experienced problems threatening their system and also in many municipalities where new systems are being installed.

MANHOLE COVERS

In many areas, some roads are resurfaced each year with a resulting slight rise in road level. Manhole tops are often buried. Tar and gravel, when used is often indescriminantly poured on manhole covers and will often seal them into place and plug the vent holes. A program should be continued to raise these manholes where necessary, to allow easy location, to prevent the entry of run-off water and stones, and to allow proper ventilation of the manhole. The road maintenance crews should be asked to co-operate fully with the sewer maintenance crews whenever a change in grade is anticipated.

PUMPING STATIONS

Pumping stations form an integral part of a sewer system and must be properly maintained in order to ensure that the sewer system does its job effectively. In many systems a pumping station if inoperative, will cause serious surcharging of the sewers and may result in flooded basements. Home owners have been known to sue for and win claims of several hundred dollars due to a pumping station failure.

In smaller municipalities, pumping station maintenance is often the responsibility of the same crew that inspects and cleans the sewers as well as operating the treatment plant. In others, the jobs may be separated.

Pumping station failures are usually the result of a mechanical or electrical failure or commonly due to objects within the sewage. Electrical and mechanical problems will not be discussed here as they will be covered in other lectures.

Many failures are due to the impeller becoming clogged with rags, small sticks, or other fibrous materials. Although the pump will run, very little sewage is pumped. Other failures occur when check valves are held open by sticks allowing internal re-circulation in dual pumping stations. Occasionally a 2 x 4 piece of lumber will stop a pump from rotating. Screens, shredding machines and other patented devices depending on reversible flow can reduce the frequency of pump problems, but introduce new problems of their own and should be avoided unless serious operating problems result. Many types of non-clogging pumps are available and should be used in preference to other devices.

It has been our experience that daily inspections of pumping stations are desirable and for some critical stations, especially those without emergency overflows, inspection 2 or 3 time a day may be found necessary. High water alarm systems are often used in these stations.

Some pumping stations have wet wells designed such that sedimentation of grit and organic materials becomes a problem under low flow conditions. Periodic cleaning and flushing is desirable to prevent odours as this material becomes septic.

As with any other part of the sewer system, records must be kept on a daily basis of the condition of the pumping station, and a regularly scheduled maintenance program is desirable. Emergencies as a result of negligence in maintenance, can become very expensive.

GENERAL

With the advent of newer industrial wastes, and the greater danger of gasoline spillages and leakages, facilities should be provided for regular testing for explosive gases, in the sewer system.

The installation of radio communication units in some of the vehicles in a larger municipality will improve the efficiency of the program, particularly in providing more rapid response to emergency blockage complaints.

Some municipalities prefer closed, one-ton utilities trucks with locked compartments. All such units should be well marked with flashing lights and adequate traffic markings. Warning signs and barriers should be erected around any opened manhole.

As the municipality grows, portable air compressors, generators, air blowers and other specialized equipment will all be acquired. Proper yard facilities are always required. Cleanliness must always be borne in mind due to the nature of the work. Safety could be the subject of a complete lecture and it is not proposed here. However, due to the possible occurrence of toxic gases and the more deadly complete

absence of oxygen, it is recommended that safety harnesses be used whenever any manhole is entered with a minimum of two men standing by at the surface.

In recent years, the innovation of sewer inspection by camera boat and closed circuit television apparatus has become quite common for larger municipalities. Many firms have gone into the business of providing this service so that a municipality does not have to purchase the equipment to enjoy the benefits.

SUMMARY

Regardless of the size of the municipality, a large per capita investment is represented in its sewer system. In order to protect this investment, confirm its public health purpose and avoid unnecessary inconvenience, it requires adequately manned programs of operation and maintenance. Average costs indicate that regular maintenance in the long run is no more expensive than furnishing emergency maintenance only.

POINT EDWARD

SEWER INSPECTION SHEETS

INSPECTED BY .... DATE ....19........

STREET ....M.H. #...........TO M.H. # ....ROUTINE ☐

EMERGENCY ☐

CONDITION OF MANHOLE # ....

MANHOLE COVER:

PROPERLY SEATED? ..............................YES....NO....

AT PROPER ELEVATION? ........................YES....NO....

MANHOLE STEPS:

REQUIRED NO. PRESENT? .......................YES....NO....

STRUCTURALLY SOUND? ..........................YES....NO....

IF A DROP MANHOLE WAS STOPPER REPLACED?..................................YES....NO....

IS MANHOLE CYLINDER STRUCTURALLY SOUND?......................................YES....NO....

REMARKS..
....
....
....

CONDITION OF SEWER

IS THERE EVIDENCE OF SAND INFILTRATION THROUGH JOINTS ....YES....NO....

IS THERE CONSIDERABLE SEDIMENTATION IN SEWER YES....NO....

DEPTH OF FLOW ....INCHES.............
TIME ....

REMARKS..
....
....
....

CHECK IF WORK REQUIRED ☐

INSPECTED BY .... DATE...19.......

STREET...M.H. #..........TO M.H.# .... ROUTINE ☐

EMERGENCY ☐

CONDITION OF MANHOLE # ....

MANHOLE COVER:

PROPERLY SEATED?.........................YES....NO....

AT PROPER ELEVATION?.....................YES....NO....

MANHOLE STEPS:

REQUIRED NO. PRESENT?....................YES....NO....

STRUCTURALLY SOUND?......................YES....NO....

IF A DROP MANHOLE WAS STOPPER REPLACED?...............................YES....NO....

IS MANHOLE CYLINDER STRUCTURALLY SOUND?......................................YES....NO....

REMARKS..
....
....
....

CONDITION OF SEWER

IS THERE EVIDENCE OF SAND INFILTRATION THROUGH JOINTS ....YES...NO...

IS THERE CONSIDERABLE SEDIMENTATION IN SEWER........YES...NO...

DEPTH OF FLOW ....INCHES ....
TIME ....

REMARKS..
....
....
....

CHECK IF WORK REQUIRED ☐

POINT EDWARD

MAINTENANCE RECORD CARD

Inlet M.H. # ....Outlet M.H. #..........................

DATE	WORK PERFORMED	HOURS	REMARKS

POINT EDWARD

SEWER MAINTENANCE CARD

Street...............................

Inlet Manhole #...................... Outlet Manhole #......................

Depth of M.H. .... Depth of M. H. ....

Invert of Inlet .... Invert of Outlet ....

Sewer Elevation.................. Sewer Elevation ....

Diam. of Sewer ....(in.) Length of Sewer ....(ft.)

Slope of Sewer ....(ft. per 100 ft.)

TOWNSHIP OF ETOBICOKE
ENGINEERING DEPARTMENT

SEWER MAINTENANCE ORDER

ISSUED BY: .... ISSUED TO: .... DATE .... TIME ....

SECTION OF .... MAIN TO BE CLEANED: ....

STREET .... FROM M.H. .... SIZE .... TO M.H. .... LENGTH ....

SEWAGE DRAINAGE AREA PLAN NO. .... PROFILE DRAWING NO. ....

CREW PERSONNEL: ....

WORK STARTED: DATE .... TIME .... WORK COMPLETED: DATE .... TIME ....

IF WORK DELYAED, STATE REASON ....

1. CONDITION OF OUTLET M.H.

MANHOLE COVER:
- PROPERLY SEATED? .................YES.....NO....
- HOLES OPEN? .......................YES.....NO....
- AT PROPER ELEVATION? ..............YES.....NO....

DO CONNECTIONS COME TO M.H? ..........YES.....NO....
IF A DROP M.H., WAS STOPPER REPLACED? .........................YES.....NO....

MANHOLE STEPS:
- REQUIRED NUMBER PRESENT? ............YES.....NO....
- STRUCTURALLY SOUND? ................YES.....NO....

IS BENCHING PROPER? ..................YES.....NO....
REMARKS:

2. CONDITION OF INLET M.H.

MANHOLE COVER:
- PROPERLY SEATED? .................YES....NO....
- HOLES OPEN? .......................YES....NO....
- AT PROPER ELEVATION? ..............YES....NO....

DO CONNECTIONS COME TO M.H.? .......YES....NO....
IF A DROP M.H., WAS STOPPER REPLACED? .........................YES....NO....

MANHOLE STEPS:
- REQUIRED NUMBER PRESENT? ..........YES....NO....
- STRUCTURALLY SOUND? ...............YES....NO....

IS BENCHING PROPER? ................YES....NO....
REMARKS:

---

3. GENERAL CONDITION OF SEWER AS SEEN FROM OUTLET MANHOLE ....
....
....
DEPTH OF FLOW ....INCHES ...... TIME ....

4. GENERAL CONDITION OF SEWER AS SEEN FROM INLET MANHOLE ....
....
....
DEPTH OF FLOW ....INCHES ....TIME....

---

5. WAS THERE ANY ABNORMAL DIFFICULTY GETTING BUCKETS THROUGH PIPE? ...............YES...NO...
IF SO, WHERE? ....
....
WAS THERE ANY DIFFICULTY IN GETTING BUCKETS THROUGH M.H.? ....................YES...NO...

6. DO YOU SUSPECT A COLLAPSED OR BROKEN PIPE? ...........................YES...NO...
IF SO, WHAT IS THE LOCATION? ....
....
....
NO. OF WORK ORDER ISSUED ....

---

7. DOES THERE APPEAR TO BE ANY INFILTRATION OF SAND INTO THE SEWER IN THIS SECTION DUE TO POOR JOINTS? ....
IF SO, WHERE? ....
NO. OF WORK ORDER ISSUED ....

8. WAS ANY OTHER OBSTRUCTION FOUND? YES...NO....
IF SO, WHAT? ....
....
IF SO, WHERE? ....
NO. OF WORK ORDER ISSUED ....

WHAT TYPE OF MATERIAL WAS REMOVED FROM THE SEWER? ....
WHAT QUANTITY OF MATERIAL WAS REMOVED? ....
GENERAL REMARKS ....
....

ODCUR CONTROL AT SEWAGE TREATMENT PLANTS

R. Kauppinen

Operations Engineer
Division of Plant Operations

INTRODUCTION

Control of odours at sewage treatment plants is, next to effluent quality control, sometimes the major operating problem. An operator should always be alert to any occurrence of an odour. There are several reasons why it is important to control odours.

The alert operator checks daily for possible odours and takes measures to prevent or correct them. Many operators become immune to odours at their plant. It is good practice, therefore, to check for carrying odours on arrival in the morning and before entering the plant grounds. Daily observations of the wind direction, the degree of humidity, the air temperature and other weather data are valuable in the event of complaints. An unofficial log of the distance and direction from the plant of any occurring odours will prove valuable.

Carrying odours can cause discomfort to near-by residents. The public often looks with suspicion on a sewage treatment plant as a real threat to the pure air they breathe. Any odours detected in the neighbourhood are immediately blamed on plant operations. In one case, there was a breakout of odour complaints in the vicinity of one of the OWRC plants. The odour was traced to a neighbouring plastics factory which was burning waste material. Complaints not infrequently come from people who, at the time, are upwind from the plant. Others may complain for political reasons or a desire to induce the municipality to purchase their property. At one OWRC operated plant a group of neighbours made a daily trip around the plant boundary hopefully testing the air. Any odours noted were immediately relayed to the City Council with the pointed reminder that their property was depreciating.

Fortunate is the operator who has never had cause for an odour complaint. However, for those of you who do have complaints about odour, you have a real public relations responsibility which is discussed more fully in another lecture.

Local odours can create a personnel problem. Although constant contact diminishes the awareness of an odour, no one enjoys a smelly job.

Hydrogen sulphide, in addition to producing an objectionable rotten egg odour, may cause damage to plant structures by the formation of a weak sulphuric acid that attacks ferrous metals and copper. Lead-base paints are also adversely affected.

Strong odours of hydrogen sulphide, mercaptins and other by-products of protein breakdown may concentrate sufficiently in enclosed structures to create a toxic condition dangerous to health.

Persistent uncontrolled odours may lead to law suits or court injunctions to cease operations.

ODOUR

Odour is that property of a substance which affects the sense of smell; a human response to the chemical structure of molecules when those molecules contact the sensory surfaces of the human body. One of the several factors in describing conditions is the genetic makeup of the perceiving individual. Also, every individual has a different level of perception which varies with his physical condition. Therefore, the measurement of odours is difficult.

Some facts about odour are:

1. A weak odour is not perceived in the presence of a strong odour;
2. Two odours of equal strength blend and produce an unrecognized odour;
3. Constant contact diminishes the awareness of an odour;
4. Past experiences affect the dislike or like of an odour;
5. In instances of mixed odour, three conditions can occur regarding the intensity of the odour sensation -
    a) subtraction (counteraction)
    b) addition
    c) synergism (enhancement).

SOURCE OF ODOUR

The most pronounced odours associated with sewage occur under anaerobic conditions. The breakdown of fats produces acids having a goat-like odour and the breakdown of proteins produces odours from hydrogen sulphide (a major culprit), mercaptins, indol, skatol and other materials.

A. Raw Sewage

Fresh raw sewage which is grey in colour has a faint odour which is not objectionable. It is a slightly pungent odour, somewhat like a damp, unventilated cellar. Stale raw sewage which is darker than the fresh raw sewage has a light, putrifying or rotten egg odour or a goat-like odour. Stale raw sewage is frequently received when abnormally large flows wash old sludge deposits out of the sewers. It can also result from prolonged detention in the collector system and from poorly ventilated sewers. A dissolved oxygen test indicating less than 0.5 mg/l indicates a septic or anaerobic condition. This in itself does not usually create a serious odour problem; however, it puts an extra load on the plant and can contribute to the build-up of odours later on.

The problem can be minimized by chlorinating or using proprietary chemicals at some point upstream from the plant. A pumping station may be a convenient place for this. Frequent flushing out of graded sewer lines in order to minimize sludge build-up is a good practice. Also, rodding and ventilation helps in many cases.

Industrial wastes usually are the source of most raw sewage odours. Meat packing, tannery and brewery wastes have characteristic odours. These can be controlled by:

1. Masking with commercial deodorants.

2. Eliminating the waste problem from the system.

3. In the case of batch slugs of odorous industry wastes, it may be possible to get the industry involved to spread their discharge time over a longer period. It is important to let those to whom you report know of this problem as soon as it appears, because much time in negotiations with the industry is required to resolve it.

B. Screen and Grit Chambers

Screen chambers, grit chambers and wet wells should be hosed as frequently as necessary. Screenings and unwashed grit should be kept in covered containers and disposed of daily, or as often as necessary by burial, burning or other sanitary means.

C. Primary Clarifier

Skimming mechanisms must be cleaned daily and the scum trough hosed down. More frequent cleaning may be required during warm weather.

The prompt removal of tank skimmings deserves special mention. Rancid greases and garbage solids are often the cause of odours. In square and circular mechanically cleaned settling tanks, an automatic surface skimming arm is usually attached to the sludge scraping mechanism. Since the sludge scrapers are usually operated continuously, or nearly so, the surfaces of these tanks should be free of scum. Operation of this type of skimming equipment requires a proper clearance for the skimming arm at the receiving trough so that the scum flows smoothly into it. If the arm bumps the trough plate, the skimmings will escape under it and reappear on the tank surface. If the arm is too high, the skimmings will flow under the arm and remain in the tank. The edge of the wiper on the skimming arm must be straight and free of curls, or it will do a poor job. Worn wipers should be replaced as often as necessary.

In rectangular tanks the skimming operation may be manual, semi-automatic or automatic. The flights, on their return voyage to the outlet end of the tank, carry the skimmings to this point for concentration behind the outlet baffle. Unless removed automatically they will continue to build up. The skimmings should be removed at least daily, or after the flights have made one or two travels over the tanks. At larger plants manual or automatic removal of skimmings may be necessary several times daily since the flights may be operated intermittently.

Sludge must not be allowed to accumulate in the clarifier. Over pumping adds an unnecessary burden on sludge handling facilities. Under pumping creates a sludge build-up which may, if accumulated too long, begin to produce gas. A daily check should be made of the sludge depth. An optimum depth should be determined which permits thick sludge to be pumped but does not hold it so long that gas is generated.

Digester supernatant is frequently returned to the primary clarifiers. If a good supernatant cannot be obtained, then it is a waste of time to return it to the plant, and it should be disposed of as digested sludge, i.e. on sand beds, vacuum filters, or hauled away wet. It can also be aerated in a superntant corrector to satisfy the immediate air demand.

D. Activated Sludge Section

There is usually a light ozone type odour in the immediate vicinity of aeration tanks. This dissipates rapidly and unless industrial waste odours are present, a normally operating aeration section is never the source of complaints. This section can, however, become upset and turn septic very rapidly.

Shortly after our new Waterloo plant had been put into operation last year, one of the check valves on the air blowers failed and the DO in the aeration section dropped to zero before the activated sludge could be removed. The plant

went into an immediate and heavy production of hydrogen sulphide which was noticeable three miles away. The air supply was immediately restored to 50% capacity, sludge was wasted as rapidly as possible and 1600 pounds of chloride of lime was added to the influent of the aeration section. It took about 24 hours to restore aerobic activities in the aerators.

It is strongly urged that a DO determination be made at least twice a day to be sure the plant is not approaching an anaerobic condition. If it is difficult to maintain a DO of at least three or four mils. per litre in the effluent, then either more air or lower mixed liquor suspended solids is indicated.

Particular attention must be paid to the condition of activated sludge. If it is deprived of air for as little as three or four hours, it will begin to go septic. Activated sludge pits should receive constant attention to be sure that pockets of stale sludge do not form. If sludge has been held in the final clarifiers too long, it may start to deteriorate. This may be corrected by chlorinating the return sludge, aeration, etc.

E. Tank Dewatering

When it becomes necessary to dewater a tank, a plan should be first worked out to ensure that the process is done in a minimal time. Frequently it is possible to dewater a tank to within six or eight inches of the bottom with existing dewatering pumps. Engineers have a peculiar habit of putting dewatering lines into the side of tanks and all too frequently locate them several inches off the bottom. This makes it extremely difficult to remove the final few inches which is usually sludge. If this part of the dewatering program is delayed for a few hours, this exposed sludge will start to decompose and your relationship with your neighbours will deteriorate at about the same rate. Rent or steal a pump to dewater the tank in about eight hours.

F. Digester

Digesters can be the biggest source of odours because they normally serve as a storage tank for both sludge and gas. Unless proper provision is made to burn the gas, it will eventually blow out through the pressure relief valve and descend on the downwind part of the neighbourhood in a nauseating blanket. Possible trouble spots to look out for are frozen gas lines to the waste gas burner, wrong number of weights on the pressure relief valve, floating cover frozen to the walls, waste gas burner pilot susceptible to being blown out, improper adjustment of diaphragm pressure valves, clogged gas lines, moisture traps in gas lines not drained, plugged up

digester sludge overflow line, liquid level in digester too low to maintain water seal at overflow pipe.

On floating cover digesters there is a space of about four to six inches between the wall and cover. This serves as an outlet for gas forming in this area. This gas can be diverted up into the dome by building up a thick scum in this space. Lacking a thick scum, it is suggested that the space be kept well limed with about six inches of hydrated lime.

Do not carry the normal waste gas burner pressure less than three inches below the digester blow-off pressure. Rather rapid gas production can result from a variety of causes and if a problem develops with a waste gas burner, it is desirable to have at least some gas storage capacity in the digester to give you time to service the burner.

During the start-up of a new digester, gas will start to be produced that is too low in methane to be burned. In order to minimize the period of bringing the digester into the methane gas production stage, it should be started with a batch of well digested seed sludge from some other digester. The pH must be kept above <u>6</u> in order to assure continued production of burnable gas.

G. <u>Vacuum Filters</u>

Vacuum filtration of sludge produces odours. These are mostly of an ammonia or barnyard variety especially in the filtration of raw sludge. Odour complaints from this source come most frequently from the families of filter operators. Raw sludge filtration gives the operator an aura all his own and sets him up as a man apart. Leave your sludge filtering work clothes at the plant.

H. <u>Chlorine Contact Chambers</u>

These chambers collect sludge and must be periodically cleaned out. The same principles apply as for primary clarifiers.

I. <u>Housekeeping Problems</u>

Proper housekeeping keeps down odours. Watch out for the following:

1. Sludge spilled by tank trucks.
2. Sludge deposited in gravel and grass by blowing foam.
3. Dirty floors and equipment.
4. Dirty tanks and launders.
5. Stagnant sewage in hard-to-drain channels.
6. Poor hydraulics in channels.

During periods of low flow, solids may tend to settle out in some of the channels. These may not be swept out during the next period of high flow and build up sufficiently to become odorous. This can be corrected by adding air diffusers in the channels or changing their cross section.

J. Sludge Beds

This is an odour source not to be taken lightly, especially where the beds are located close to residences. Partly digested sludge does not drain easily and can continue digesting right on the bed. If this should happen, decant all the liquid that you can and if the problem warrants the expense, remove it by truck and determine how to avoid putting green sludge on the bed. Ripe sludge does not have an objectionable odour. Be careful not to run new sludge over old in the spring. There may still be an ice cover on top of the sand and the new sludge will then not drain.

K. Persistant Odours

Perhaps the most difficult problem to deal with is an overloaded plant. The digesters may not provide sufficient time to produce a well digested sludge. The air compressors may not have sufficient capacity, etc. Where there is a difficulty of this type, two things can be done. Use commercial deodorant and complain bitterly to the owners of the plant that only through a renovation and expansion program can the odours be eliminated.

CONTROL OF ODOURS

A number of commercial products are available to mask odours. These frequently have a place in sewage plant operation, particularly where a temporary upset is the cause of an odour. However, they should never be substituted for cleanliness and proper operation. If they are used, the manufacturer should be consulted in their proper application. Most of them are quite expensive and can be wasted if not used in the proper manner. Some are mixed with the incoming sewage, some are sprayed on the surface of an odour producing area and some are fogged into the atmosphere.

Chlorine is used as an odour control agent which is easy to apply and reacts rapidly. Depending on the problem, the point of application has to be determined. The dosage can best be determined by experience and it can be applied to raw sewage, return sludge, supernatant, etc.

Sodium nitrate, zinc sulphate and various chlorine compounds such as chlorinated benzene have been used to control odours. Their use is limited because of their cost.

Ozone is a powerful oxidizing agent. Ozone is a form of oxygen which has three atoms (O_3) as compared to the normal oxygen molecule which has two atoms (O_2). The third atom is very unstable and quickly reacts with oxidizable matter. Ozonizers produce ozone by the passage of a high tension electric discharge through oxygen or air in an enclosed chamber. Ozone can be introduced to the liquid or dispersed into the atmosphere.

The use of activated carbon has been found to be advantageous in the control of odours in addition to other advantages it provides. The peculiar properties of activated carbon are due partly to the adsorptive properties of its particles. Activated carbon is used in the form of a powder that may be applied by a dry-feed machine directly to the sewage or sludge to be treated. Practically all the benefits claimed for activated carbon can be obtained by applying a dose of 35 to 50 lbs. of carbon per million gallons of sewage treated. In general, the carbon should be added just after the screens, although other points of application have been used with satisfactory results.

RECORDS AND REPORTS

B. W. Hansler

Operations Engineer.

INTRODUCTION

A section from the Texas Water and Sewage Works Association Manual for Sewage Plant Operators reads: "The importance of keeping complete and accurate records cannot be over-emphasized. The proper administration cannot be realized without adequate attention to this phase of work". More simply, the maintaining of adequate plant records is the keystone to good plant operation.

In particular, the following items will be discussed:

1. Purpose and value of records
2. Types of records
3. Good record completion practice

PURPOSE OF VALUE OF RECORDS

Maintaining adequate records in a sewage treatment plant has a multitude of purposes:

1. A guide to a systematic way of evaluating plant performance. The past history of performance can be plotted on graph paper where trends may be seen and the acceptability of the plant effluent may be readily judged over different periods of time. That is to say, adequate records are an aid to better operation.
2. Proof of effective operation.
3. Proof of performance to justify decisions, additional expenditures and recommendations.
4. Basis of reports to government, health departments or other agencies.

5. Combined with information the operator might recall from memory, good records can form a sound defence in the event of a law suit.

6. Used in connection with a public relations program if performance is good.

7. Inspiration to operator to excel past performance.

8. Journal for future reference.

TYPES OF RECORDS

Records which should be maintained at a sewage treatment plant may be separated into three main classifications:

a. Records of a descriptive planning or inventory type related to the physical plant.

b. Records of operation.

c. Records of maintenance and lubrication.

Physical Plant Records

Descriptive, planning or inventory type records relating to the plant should be available for reference. Records of this type include the following:

1. Report of consulting engineers, including basis of design, capacities of all plant units, population served, service area and other usual information.

2. "As Constructed" plans and specifications on the entire plant.

3. Shop drawings and operating instructions for all equipment.

4. Detailed plans of all piping and electrical wiring.

5. A complete record on each piece of equipment, including name of manufacturer, cost, rated capacity, dates of purchase and installation and performance curves. This information in the OWRC is recorded on white cards known as Maintenance Data Cards.

These records are of particular value in operating the plant performing maintenance on equipment and in replacing equipment.

The plans and specifications provide the operator with information that he requires to operate the plant. For example, volumes of various units as clarifiers, digesters and aeration tanks are used to determine detention times. From this information, the number of units required in operation can be determined. In addition, the volume of the aeration tanks is used in conjunction with the sewage flow to determine the suspended solids concentration in the aeration tanks.

The use of shop drawings and operating instructions is fairly well self-explanatory in the maintenance and operation of the plant equipment.

Further complete records of each piece of equipment make replacement an easier task in that all the information necessary for ordering new components is easily accessible.

Operation Records

At each plant, data on operation to be collected, analyzed and reported should be dependent on the particular and peculiar needs and circumstances governing operation. Records should never be made for the sake of records. Each measurement, observation and calculation should be justifiable on the basis of expected usefulness and value.

Operation records are usually separated into four main classifications:

I Daily performance records

II Laboratory records

III Log book

IV Annual report

The daily performance records should contain all the numercial and visual data of importance connected with the daily plant routine. These records are usually classified according to treatment units and are presented in a tabular form. Measurements of raw sewage flow, grit removal, screenings removed, sludge pumped, power consumed, chlorine consumed, sludge hauled and filtered etc., are examples of the types of data that should be recorded. It is advisable to summarize the most important figures on one sheet for ease of reference.

The laboratory control sheet is an orderly record of all lab tests. At small plants particularly and even at larger ones, this record can be included in the daily performance record.

Where facilities permit, results of the following tests at the various stages of treatment should be recorded.

Temperature	Chlorine Residuals
Total Solids	Settled Solids
Fixed Solids	Volatile Solids
pH	BOD
Dissolved Oxygen	Sludge Index
Suspended Solids	Etc.

By careful recording of these values and study of their change, it is possible to adjust the treatment process for optimum treatment results.

There are many miscellaneous incidents that occur constantly in plant operation that do not fit into the daily performance sheet. If these incidents are of sufficient importance, they should be included in a log book. Samples of information that should be recorded in a log book are as follows:

1. Results of a daily plant and equipment check.
2. Special maintenance performed other than routine procedures.
3. Equipment breakdown and service calls.
4. Unusual changes in the treatment process.
5. Accidents to personnel.
6. By-passing plant units.

7. Visits from municipal officials, consultants, control agency or others.

8. Special instructions issued.

9. Complaints registered.

The information recorded in the log book is often valuable for later reference.

At the end of the year, an annual report of the year's operation should be written. Information in the annual report should comprise plant performance data, annual cost figures and other highlights of the year's operation. Plant performance data should consist of data presented on a monthly basis both graphically and by charts. The annual report serves as a permanent and readily accessible record of the plant's operation and can be easily used to compare the operation of previous years. Plants operated by the OWRC have annual reports prepared by head office staff. However, operators of plants not operated by the OWRC should attempt to prepare annual reports, if they do not already do so and even if only operating data is included.

Maintenance and Lubrication Records

Maintenance and lubrication records should not be neglected when setting up a record system at a plant. Most important, lubrication records guarantee that every mechanical component will receive proper lubrication. Maintenance records will indicate the amount of time and money that have been spent on maintenance of major components. The OWRC utilize the following methods for lubrication and maintenance records and have found these methods quite successful.

Lubrication data is entered on a set of cardboard cards filed neatly in a file cabinet which is often a small metal box. Equipment requiring maintenance on a regular basis is also included in the lubrication records.

These records are divided into 12 sections. Each section represents a month of the year. Data concerning components lubricated and checked on a monthly basis, every three months, every six months and annually are recorded on blue, green, orange, and yellow cards respectively. Components that are lubricated and checked on a weekly and daily basis are not included

as they eventually become habitual. Each card contains the name of the equipment and components to be lubricated, type of lubricant to be used and frequency of lubrication. This type of information also applies to equipment receiving regular maintenance. On the back of the card, space is provided for the date that the particular lubrication and maintenance was performed. On the top right-hand corner, the following group numbers are printed to designate the types of equipment to be lubricated and checked:

<u>Group I</u>

All pumps

<u>Group II</u>

Blowers, compressors, vacuum pumps, exhaust systems.

<u>Group III</u>

Clarifiers, barminutor, comminutor, coil filters, mixers.

<u>Group IV</u>

Electrical

<u>Group V</u>

Flow meters

<u>Group VI</u>

Boilers and furnaces

<u>Group VII</u>

Buildings

<u>Group IX</u>

Digesters and digester control equipment.

To clarify how the card system is used, an illustration will be given. Consider the month of June. At the start of June, all the cards in the June file are removed and the proper lubrication and maintenance is performed. Then according to the next lubrication and maintenance period, these cards are moved ahead and filed in the appropriate month file. That is to say, work to be done monthly is moved ahead to the July file; work to be done on a three month basis is ahead to the September file and so on. All the cards in a section are reviewed on a monthly basis and the cards then filed in the monthly files of the next lubrication and maintenance date.

A file should also be provided for maintenance records. The major purposes in keeping proper maintenance records are to ensure that maintenance is performed on a regular basis and in addition, to keep records of the maintenance performed on each piece of equipment.

Maintenance to be performed on a scheduled basis is recorded on coloured cards and filed on a monthly basis. The OWRC uses the following coloured card scheme; white, green, orange and yellow cards are used to designate scheduled maintenance that is to be done on a daily, monthly, quarterly, semi-annually and yearly basis. Yellow cards are also used to designate scheduled maintenance that is to be done on an interval greater than one year.

When scheduled maintenance is performed as specified on the card, it is recorded on the back of the card along with the date the maintenance was performed. In addition, information concerning the repairs and cost involved are recorded on the maintenance data cards which were discussed under physical plant records. This data is also recorded on a (white) Repairs and Alterations card which is mailed to head office in Toronto for consideration.

If there is an emergency breakdown or if there is maintenance which is required and is not scheduled, work done is recorded on an (orange) Repairs and Alterations card which is also mailed to head office in Toronto for consideration plus the Maintenance Data card which is filed at the WPCP.

The coloured cards previously mentioned are identical to those cards used in recording lubrication data.

The important point to remember is that these records should be kept simple otherwise they will become burdensome and eventually will probably be dropped due to a lack of interest and time.

GOOD RECORD COMPLETION PRACTICE

Care should be exercised in completing records to ensure that they are clear, concise and neat. Records that are poorly kept and slovenly written tend to be difficult to read and, in addition, tend to discourage reference due to their appearance and incompleteness. This point cannot be emphasized emphatically enough.

The information should be accurate, uniform and presented in common familiar units. Care must be exercised not to confuse U.S. gallons with Imperial gallons. This is especially important as a great deal of data and machinery used at sewage treatment plants comes from the United States. Remember also, that flow meters and power consumption meters often have multiplying correction factors built-in and it is always necessary to make the adjustment before entering the figures.

The importance of the tiny decimal point can never be underestimated for without this, figures lose all meaning. Make sure that when decimals are used, the position of the point is clearly indicated and where the numer quoted is a fraction, the point should always be preceded by a zero.

After the records have been completed in a suitable manner and analyzed, it is important to have a filing system for protection purposes and to make the records readily accessible.

CONCLUSIONS

Records aid in operation, show the efficiency of the plant, provide for future reference and encourage the operator to excel previous performance. The ultimate value of the effort in keeping records will be determined by the completeness, accuracy and value of the information gathered. If the operator uses these records instead of being a slave to them, they will help him to operate the plant more efficiently and economically.

There is no better way to claim efficiency and economy than to have a good set of records to prove it.

Date Due

OCT 17 1968			
JUN 16 1970			
NOV - 9 1970			
FEB 3 1971			
SEP - 6 1971			
NOV 19 1971			
OCT 27 1972			